ASPHALT CONCRETE PERFORMANCE ANALYSIS BY USING WASTE TIRE AS A PARTIAL REPLACEMNT OF ASPHALT BINDE

BY

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DECLARATION

I hereby declare that this thesis entitled **“Asphalt Concrete Performance Analysis by Using Waste Tire as a Partial Replacement of Asphalt Binder**“was composed by myself, with the guidance of my advisor, that the work contained herein is my own except where explicitly stated otherwise in the next, and that this work has not been submitted, in whole or in part, for any other degree precision qualification.

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This is to certify that the dissertation prepared by **Mr**. **Bekele Dessie** entitled **“Asphalt Concrete Performance Analysis by Using Waste Tire as a Partial Replacement of Asphalt Binder**“ and submitted in fulfillment of the requirements for the degree of Masters Science in Civil Engineering complies with the regulation of the University and meets the accepted standards with respect to originality and quality.

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ABSTRACT

For a country like Ethiopia, an efficient road network is necessary for national integration, industrial and socio-economic development. Due to improvement in living standards of the people, the use of vehicles has increased drastically over the last few years. The importance of road transport over other forms of land transport rise because the rapid growth of the population of the country and migration from rural to urban area has led to increase in traffic volumes and road building activities.

Waste tires are tires that completed their service life and they come mostly from passenger cars and trucks. Now a days the large volume of waste tires rubber becomes worldwide serious problem that affect the environment. The use of recycle waste tire as a replacement of asphalt binder for asphalt pavement has been investigated in this research.

The study compares bitumen binder and binder modified by Waste Tire using laboratory tests including rheological, conventional test and Marshall Flow and stability with corresponding volumetric properties. Including the control specimen five binders were obtained by mixing the asphalt binder with four different percentages of Waste Tire by weight of asphalt binder (10%, 20%, 25% and 30%) for rheological test and for conventional and marshal test used three sample excluding the control specimen (20%, 25% and 30%).

The rheological binder tests were conducted using a Dynamic Shear Rheometer. Those tests are; Amplitude Sweep Test, used to determine the Linear Visco-Elastic Range of the binders at which the temperature ranges from10C^{o} to 54.4 C° with constant frequency which is 10rad/s. Frequency Sweep Test, used to develop the master curve and determine the rheological properties of the binders over a wide range of temperatures and frequencies. Performance Grade is done to find out the performance grades of the binder at higher temperature. Multi-Stress Creep and Recovery test has done to determine the rutting parameter (J_{nr}) and percentage recovery of the binder. Other tests like conventional tests are performed to check the effects of Waste Tire in penetration, ductility, softening point and flash point tests. Marshall Mix design also performed to quantify the Optimum Binder Content in the asphalt mixture.

In order to check the economic feasibility of partial replacement of bitumen binder by waste tire a simple economic analysis was done and according to the result found, it is economical to use waste tire as a partial replacement of bitumen binder.

From amplitude sweep test the proportion of waste tire increased from 10% to 20% the linear visco elastic range increased with temperature whereas further increased waste tire from 20% to 30% the linear visco elastic range decreased with the same temperature but it is within the limit. It shows that waste tire reduce the flexibility of the bitumen binder. Master curve developed using frequency sweep test showed that waste tire improves the shear modulus at low frequency and high temperature. Using multiple stress creep recovery waste tire containing binders have shown less total strain than bitumen binder at higher temperature means that waste tire improves the rutting performance of the bitumen bonder. According to Marshall Mix Design waste tire replaced binder showed that good stability, flow and volumetric properties. Overall, the research indicates that, it is feasible to partially replace asphalt binder by waste tire up to 20% is preferred.

Key words: Waste Tire, Bitumen, FST, AST, MSCR, PG and Marshal Mix Design

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LIST OF ABBREVATIONS

AASHTO	American Association of State Highway and Transportation Officials
AST	Amplitude Sweep Test
ASTM	American Society of Testing Materials
AV	Air Void
ERA	Ethiopian Road Authority
DSR	Dynamic Shear Rheometer
FHWA	Federal Highway Agency
FST	Frequency Sweep Test
HMA	Hot Mix Asphalt
LVER	Linear Viscoelastic Range
MSCR	Multiple Stress Creep and Recovery
OBC	Optimum Bitumen Content
PAV	Pressure Aging Vessel
PG	Performance Grade
PR	Percent Recovery
RAC	Rubber ASPHALT Concrete
RTFO	Rolling Thin Film Oven
Super pave	Superior Performing Pavements
SHRP	Strategic Highway Research Program
VFA	Void Filled with Asphalt
VMA	Void in Mineral Aggregate

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Chapter One: Introduction

1.1. Background

For a country like Ethiopia, an efficient road network is necessary for national integration, industrial and socio-economic development. Due to improvement in living standards of the people, the use of vehicles has increased drastically over the last few years. The importance of road transport over other forms of land transport rise because the rapid growth of the population of the country and migration people from rural to urban area that led to increase in traffic volumes. In addition, due to increasing weights, volumes of traffic using the roads and the complex gear configurations of trucks, it has become necessary to pay more attention to the use of a more realistic and rational assessment of pavement material behavior, particularly in terms of dynamic stress-strain responses.

Bitumen is widely used as a binder material in the construction of pavements in Ethiopia and throughout the world. It is a viscoelastic material, meaning that its response under a given condition of stress or strain depends not only upon the current state of stress or strain, but also upon its loading history.

Rubber technology is famous and quite effective for flexible pavement in high temperature zone. As we know Ethiopia has different temperature ranges from lower to higher (Gambella, Afar, etc. area have higher temperature and Debrebrhan, Bale, etc. area, have lower temperature). Therefore using waste tire as binder material for Ethiopia is suitable.

Rubber asphalt can protect the deformation due to the viscous property of asphalt concrete as well as other effects from heating such as bleeding; rutting and so on further more this material can reduce the noise due to the vibration of paving structure in traffic condition, which is a valuable benefit for road pavement in urban area (Tomas U. GanironJr, 2014).

Crumb rubber has been used to modify the asphalt binder in a process in which the rubber is blended with asphalt binder. The modified binder is commonly referred to as asphalt-rubber. Use of crumb rubber in hot mix asphalt concrete reduces life cycle cost of pavement because of less maintenance required (A. S. M. Ashek Rana, 20046). This material makes a new breakthrough for modern construction materials and methodology due to the impact of scarce resources and economic constraints. According to technical surveys, there is an increasing rate of adopting this kind of material as a modifier for roads construction in different parts of the world. Advantages using waste tire as a binder include decreased rutting, reflective and thermal cracking, and better de-icing properties and reduced traffic noise (Dubois, E., 2014).

The Federal Transport Authority Disclosed Currently the number of cars in Ethiopia has exceeded 831,000. From the Authority commented the number of cars imported had increased as the nations and its citizen's economy grew. The number of cars in Ethiopia last year was 708,410, however, now it has reached 831,265. From the entire number of cars, 62 percent of them are found in the nation capital, Addis Ababa (Source Walta Information Center March 2018).The number of waste tires disposed from the survey made estimated 12,834,728 per year (these number will be changed according to the number of vehicles found in the country per year). From those disposed tires insignificant of them used for different purposes but most of them burnt or disposed of improperly. Using of this material as a partial replacement of asphalt binder will have two benefits for the country. One by using the rubber material replacing some percentage of the asphalt binder will decrease bitumen import and will save the need for foreign currency. The second benefits when using the waste tire as binder material, we are cleaning our environment and solving problems that come from the disposed tires.

1.2 Problem of the Statement

Ethiopia is one of the developing countries and allocates most of its budget on infrastructure. Roadway construction is one of them and most of the paved roads here are flexible pavement, therefore, it is important to work on improvement in performance as well as cost effectiveness by using modified binders. As a result, the use of waste tire that is locally available material as an alternative replacement for asphalt binder in HMA could be a possible solution.

Nowadays developed countries use performance based asphalt binder tests including their specifications that are super pave grading system. Tests like more advanced binder specification method using Multiple Stress Recovery (MSCR) test has been test more developed. MSCR test more advanced because it can predict the rutting performance of the binder as well as it is convenient to consider different levels of traffic.

In Ethiopia still conventional binder tests and specification system is in use. Therefore, it is important to bring a change towards binders' characterization, which will help to prepare specifications for asphalt binders according to performance grade and able to produce modified binders with improved rheological properties to increase pavement performances by minimizing rutting and other asphalt distresses.

1.3. Objective of the Research

1.3.1. General Objective

The objective of this study is to evaluate the use of waste tire as a partial replacement of asphalt binder by performing practical experiment and to show the percentage replacement of bitumen by waste tire.

1.3.2. Specific Objective

- ♦ To determine the rheological properties of binders containing waste tire by developing Master Curves using frequency sweep test
- ♦ To determine visco-elastic ranges of binders using Amplitude Sweep Test
- ♦ To determine the rutting performance of the binders containing waste tire using Multiple Stress Creep recovery
- ♦ To determine the performance grade of the binders containing waste tire for comparison
- ♦ To determine optimum binder contents of the mix using Marshal Mix Design
- ♦ To determine the quality of the binder containing waste tire using conventional tests

1.4. Research Question

- •How much percentage bitumen binder can we replace with waste tire?
- •Is waste tire replaced bitumen binder less affected by short term aging (RTFO) than bitumen binder?
- •Is waste tire partially replaced bitumen binder with better rutting performance than bitumen binder?
- •Is it possible to use waste tire as a binder material with less cost incurred than bitumen binder?

1.5. Significant of the Research

- »Using waste tire as a partial replacement of bitumen binder, itwill reduces the amount of imported bitumen as well as decrease foreign currency.
- » Using waste tire as a binder material will reduce environmental pollution that come from waste tires.

»It will create job opportunity when the research is implemented.

»It will open a door for other researchers to search for alternative binder materials to replace the non-renewable bitumen binder.

»Reducing periodic maintenance of the paved road

1.6 Scope

The experimental work undertaken in this research has been divided into two main parts:

1. DSR Test, penetration, ductility, flash point and softening point for binder and
2. Marshall Mix Design Test for asphalt mixture.

For DSR test binders selected both modified and ordinary conditions and studied in both their unaged and aged conditions to compare the results for these two situations. Dynamic mechanical tests were performed using a Bohlin stress controlled Dynamic Shear Rheometer (DSR) with parallel plate configuration in an oscillatory shear mode. Tests were conducted in four types:

♦ Amplitude sweep tests

♦ Frequency sweep tests

♦ Performance Grade

♦ Multiple Stress Creep Recovery

1.7. Limitation of the Research

Due to time and economical limitations and lack of certain testing equipment’s the following tests were not conducted detailed moisture susceptible test, life cycle cost analysis for roads constructed using waste tire in comparison to those constructed using conventional asphalt binder, Characterization of the chemistry of binders composed of waste tire and asphalt binder Long term aging which requires Pressure Aging Vessel (PAV).

Chapter Two: Literature Review

2.1. Introduction

This chapter summarizes the principal findings from a review of selected literature concerning the use of recycled waste tire as binder material for asphalt concrete and its importance. And also the origin and properties of ordinary binder, and different test methods essential for this thesis.

2.2. Waste Tire

As vehicles are used frequently, the wear and tear of their tires is obvious. Due to wear and tear of tires, the life of tire reduces and at last, it becomes useless. These tires are disposed easily by either burning or by dumping. Disposal by burning causes air pollution and dumping causes valuable land to be wasted for stacking up the tires. As disposal of waste tires has become a worldwide problem and has caused worry to administrators, researchers and environmentalists. So an attempt to use this waste tire rubber for improving the properties of bitumen by blending it with crumb rubber and ultimately a new method to be introduced to reduce pollution problems and protect our environment (Mr. Petkar Deepak Ganesh and Miss. Mane Priyanka Arun, 2013).

2.2.1. Waste Tire Modified Asphalt

The modification of bitumen with rubber started in the early 1840's in the USA with the purpose to develop a road surface treatment with higher elasticity. The goal was to enhance the elastic properties of the binder through the addition of natural (latex) and synthetic rubber (crude oil based polymers). Since then, on-going development had continued until the early 1960s, when Charles McDonald, materials engineer for the City of Phoenix, succeeded in creating an asphalt mix with rubber crumbs (Abdullah Karri Sandra Hellwig, 2015).

Whether it is processed in either the wet or the dry approach, the crumbed rubber used in asphalt surfacing applications has several other advantages other than improved resistance to skidding. It also provides asphalt mixtures with high shear strength, which is favorable in withstanding imposed traffic load and preventing the occurrence of rutting in the underneath pavement layers (Behzad Rahimzadeh, 2002). Principal differences between these processes include size of rubber (much coarser rubber is used in dry process than in wet process), amount of rubber (the dry process uses 2 to 4 times as much as the wet process), function of rubber (in the dry process the rubber acts more like an aggregate but in the wet process it acts more like the binder), and ease of incorporation into the mix (in the dry process no special equipment is required while in the wet process special mixing chambers, reaction and blending tanks required) (Arashotamed, Amit Bhasin & AnooshaIzadi, 1950). The wet process in general is used to modify binders with crumb rubber before being incorporated into either asphalt mix or spray applications such as chip seals. The main advantage of this process compared with the dry process is much greater interaction between the crumb rubber and the bitumen is possible, and extensive modification of the bitumen achieved. Oils from the bitumen are absorbed into, swell and partially disperse the outer surface of the crumb rubber particles (JP Wu, PR Herrington and K Neaylon, 2015). Studies in northern and central Arizona on asphalt-rubber mixes showed that these modifications increase resistance against aging to a small degree. Moreover, increased resistance to hardening and improved fatigue life has been indicated as well as decreased sensitivity to temperature changes. The greatest benefits of asphalt rubber hot mix overlays were the reduced layer thicknesses and the associated reduction in the material usage and maintenance costs. Both chip seals and the hot mix overlays were found to have a great effect on reducing the reflection of alligator cracks, however the hot mix overlay provided a better riding surface and decreased traffic noise (Abdullah Karri Sandra Hellwig, 2015).

Waste Tire used as an aggregate up to a maximum size of 12.5 mm in Rubber Asphalt Concrete (RAC) as a replacement for traditional large aggregates results in a weaker mix than without rubber. Since rubber is not as hard as the crushed stone aggregates, it follows that the Marshall stability of an asphalt-aggregate-chunk rubber mix would be lower than a mix without chunk rubber. However, it was also surmised that the larger rubber chunks tend to absorb some of the energy imparted to compact a RAC sample, resulting in a weaker aggregate structure than a mix without any chunk rubber (.A. S. M. AshekRana, 2004).

Nowadays waste tire used as a partial replacement of the binder used different parts of the world. The rising cost of construction and need to contribute to the solution of the ever-growing environment backlog problems the study paved the way for the recognition of using waste tire as an asphalt cement modifier for road construction to solve the current issues on waste disposal (Tomas U. Ganiron Jr, 1996)**.** The use of waste tire rubber as an additive for asphalt cement has been developing 25 years. Initial experimental use of waste tire rubber focused on the possible added performance benefits that the rubber imported to the pavements in which they were incorporated (WSDTPRT, 1992).Waste tire in Canada using different percentages with different purposes, using 10% waste tire in road construction applications include but not limited to rendered temperature susceptibility, fostered rutting and fatigue resistance, and increased stability and reduced flow value and improving stripping resistance. When added to asphalt binder up to a percentage of 30%, significant enhancement in properties such as weathering and stripping resistance have been achieved (M. Abukhettala, 2016). The research performed in the United States of America, Texas both laboratory and field monitoring by using 16% of waste tire proportion by weight. Visual distress survey conducted in summer 1998 and 1999. From the visual distress survey included a pedestrian survey to find out extent and severity level associated with pavement distresses such as alligator cracking, transverse and longitudinal cracking, rutting, and potholes does not reveal any noticeable distress. Therefore, this crumb-rubber pavement section did not require any major maintenance ever since it was open to traffic .Use of crumb rubber in hot mix asphalt concrete reduces life cycle cost of pavement because of less maintenance required (Y A. S. M. Ashekrana, 2004).

India practicing using waste tire as partial replacement of binder by installed plants at various locations across the country in North, South, East and Western parts for the manufacturing of crumb rubber powder from scrap tires . They are at present processing over 3000 MT of crumb rubber every month and currently consuming around 30000 – 35000 MT of scrap tires annually. Processing waste tires thru ambient mechanical grinding process, the breaking up of a scrap tire happens at ambient temperature. It's completely environment friendly process (Tinna Rubber & Infrastructure Limited, INDIA, 2015).

2.3. Waste tire processing plants

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The capacity of recycling industry in Slovakia is larger than the amount of used tires, which is produced in this country. Utilization of ground rubber in road surfaces as an admixture to asphalt mixes can improve profitability of this branch of industry and in this way also to induce interest in recycling used tires in more extensive way. There are a large number of used tires from the past, a lot of them ended up at waste storage sites. Development of new materials with ground rubber which will be of better characteristics than these which are used now will help to accelerate waste tires recycling and waste tires could disappear from environment in the next few years (A. S. M. Ashek Rana, 2004). Crumb rubber has been successfully used in asphalt and chip seal surfacing internationally for many decades, particularly in asphalt mixes in the US and as a chip seal binder in Australia and South Africa. Plant, equipment and extensive guidance on the use of crumb rubber in asphalt and chip seal surfacing is readily available internationally and could be readily applied or adapted to crumb rubber use in New Zealand (JP Wu, PR Herrington and K Neaylon, 2015).

2.4. Environmental Concerns

Several environmental studies in the US have demonstrated that the emissions from crumb rubber asphalt mix production and paving operations are not significantly different from conventional processes and the detectable levels are normally within limits set by US Government agency guidelines. For the recycled crumb rubber mixture, volatile organic compound emissions were lower than the range for standard HMA. The report pointed out that air quality did not seem to be any more of a severe problem than it was with conventional asphalt. Due to odor, cold or very low heat, milling was preferred over hot milling when recycling the crumb rubber pavements. Any hot in-place recycling could only be done with equipment trains having effective emission control systems on them (JP Wu, PR Herrington and K Neaylon, 2015).

Generally relevance of the research is using waste tire as a partial replacement of bitumen binder here in Ethiopia, reduce rutting that come from high temperature, reduce costs of bitumen, will create job opportunity for the young Ethiopians when the research implemented, Etc.

2.5. Asphalt Concrete

Asphalt concrete is a composite material commonly used in construction projects such as road surfaces, airports, parking lots and sometimes for walkways. Asphalt concretes are a mixture of mineral aggregate, filler and bituminous binder, which form an interlocking structure. This interlocking aggregate structure is the major contributor to the strength and performance of the laid material. The strength of the asphalt concrete mainly depends on quality of the binder and aggregate materials, Mix proportion and construction process.

2.6.1. Hot Mix Asphalt (HMA)

Hot Mix Asphalt consists of a combination of aggregates uniformly mixed and coated with binder. To dry the aggregates and obtain sufficient fluidity of asphalt cement for proper mixing and workability, both the aggregate and the asphalt must be heated before mixing-hence the term hot mix. Regardless of the design procedure used, the design of an HMA mix consists of the following three steps:

1. Selection of the type and gradation of mineral aggregate
2. Selection of the type and grade of asphalt binder
3. Selection of the amount of asphalt binder to satisfy the project specific requirement (Dubois, E., 2014).

2.7. Aggregates

Aggregates are hard, inert materials such as sand, gravel, crushed rock, slag, or rock dust. Properly selected and graded aggregates are mixed with the asphalt binder to form HMA pavements. Aggregates are the principal load- supporting components of HMA pavement. Aggregates can be classified to three types according to their size distribution: coarse aggregates, fine aggregates, and mineral filler. Coarse aggregates are generally defined as those retained on the 2.36-mm sieve i.e. it comprise the portion of the aggregates that has large particle sizes. Fine aggregates are those that pass through the 2.36-mm sieve and are retained on the 0.075-mm sieve. That is, the aggregate particles that can fill the voids created by the coarse aggregates in the mixture (Dubois, E., 2014). Mineral filler is defined as that portion of the aggregate passing the 0.075-mm sieve. It consists of very fine, inert mineral with the consistency of flour, which is added to the hot mix asphalt to improve the density and strength of the mixture. Mineral fillers can also be classified in two based on their ability to react with asphalt binder these are active fillers and inactive fillers.

2.7.1. Aggregate Gradation

An aggregate's particle size distribution, or gradation, is one of its most influential characteristics. In HMA, gradation influences almost every important property including stiffness, stability, durability, permeability, workability, fatigue resistance, frictional resistance and resistance to moisture damage. Because of this, gradation is a primary concern in HMA mix design and thus most agencies specify allowable aggregate gradations. Inappropriate selections of aggregate gradation, aggregate properties, and binder grade, type and content are major contributors to rutting and cracking of HMA pavements. The effect of gradation on HMA performance has long been a controversial issue. Strong opinions exist among industry experts as to which gradation type, ranging from fine to coarse to open-graded or stone matrix bituminous gradations, will provide the best performance.

The mixture resistance to permanent deformation is highly dependent on the aggregate structure. Several research studies have agreed that giving more importance to the aggregate gradation would be the solution for pavement rutting (Schramm, G., 2000). Aggregates are expected to provide a strong stone skeleton to resist repeated load applications. Shape, surface texture, angularity and gradation have a great influence on HMA performance.

2.8. Origin and properties of Bitumen

Bitumen is the residue of certain crude oils after the removal of the volatile components. The formation of natural bitumen and that produced by the distillation of crude oil are similar. However, the production of bitumen obtained by distillation is quicker, although it requires higher production temperatures. Nowadays, bitumen used in road construction is generally manufactured from refined crude oil. There are about 1500 different crude oils produced throughout the world but only a few of these are suitable for the manufacture of bitumen. The main sources of crude oil are the United States, the Middle East, the countries around the Caribbean and the countries of the former Soviet Union (Yazan Issa, 201637).

The important characteristics of bitumen depend on the mix type and construction. In general, bitumen should possess the following properties.

• Should not be highly temperature susceptible, i.e., during the hottest season the mix should not to become too soft being unstable and also during cold season the mix should not to become too hard being brittle causing cracks.

• The viscosity of the bitumen at the time of mixing and compaction should be adequate. This can be achieved by use of cutbacks or emulsions of suitable grades or by heating the bitumen and aggregates prior to mixing.

• There should be adequate affinity and adhesion between the bitumen and aggregates used in the mix (Hand and K. Galal, 2001)

2.8.1. The Viscoelastic Nature of Bitumen

Bitumen's are viscoelastic materials. Behavior of these materials combines two parts: elastic behavior and viscous behavior. Materials with elastic behavior return to their initial state after removal of the applied loads, whereas permanent deformations remain under applied loads under viscous behavior. Several factors affect the behavior of viscoelastic materials in terms of their elastic and viscous behavior. Temperature is the most critical of these parameters. Viscoelastic materials have behavior that is more elastic at low temperatures, whereas they behave more viscously at high temperatures. The second parameter, which has an effect on viscoelastic materials, is loading time or rate of loading. Bitumen behaves like an elastic solid at high rates of loading, whereas it behaves as a viscous liquid at long times of loading. Therefore, to conclude, at a fixed temperature, long times of loading correspond to high temperature behavior (more viscous) and at short loading times the response shifts to low temperature behavior (more elastic). Bitumen, therefore, exhibits high stiffness and brittleness at short times of loading, whereas it is linked with high ductility and exhibits low stiffness at long loading times (JP Wu, PR Herrington and K Neaylon, 2015).

2.9. Rheology

Rheology is the science of deformation and flow. It is a branch of physics and physical chemistry since the most important variables come from the field of mechanics: forces, deflections and velocities. The term "rheology" originates from the Greek: "rhein" meaning "to flow". Thus, rheology is literally "flow science". However, rheological experiments do not merely reveal information about flow behavior of liquids but also about deformation behavior of solids. The connection here is that a large deformation produced by shear forces causes many materials to flow (Tomas U. Ganiron Jr, 2014).

2.10. Dynamic Shear Rheometer (DSR)

Dynamic shear rheometer used to measure viscoelastic properties, fatigue and rutting resistance at high and intermediate temperature. DSR measures both viscosity and the elastic properties of the asphalt binders. Dynamic Shear test is performed by rotating the top plate in an alternating clocke wise and anticlockwise position with respect to a zero position.

The parallel plate geometery used in this test method is applicable to asphalt binders that behave as a linear viscoelastic material. The modulus (G*) for linear viscoelastic material depends on temperature and the rate of loading (frequency) but does not depend on the magnetude of the load used to measure the modulus. The modulus for a non-linear viscoelastic materialvaries with the magnitude of the applied load for a given frequency and temperature.

This test method provides a means for measuring the complex shear modulus and phase angle at 10rad/s and at a temprature from $3C^0$ to $88C^0$. These limits are given to ensure that the DSR can be used to test all binder gradeds. The device may be used at other temperatures and frequencies as long as the torque is sufficient (stiff material) or the resolution is sufficient to give reliable test results (soft material).The test procedure is valid only asphal binders if the complex shear modulus is between 100Pa and 10MPa. The 8mm plate is used for temperatures ranging from $4C^0$ to $40C^0$ and the 25mm plate is used for temperatures ranging from $46C^0$ to $86C^o$.

The temperatures of the test specimen must be maintained at $\pm 0.1C^o$ by enclosing the upper and lower plates in a temprature controlled chamber.

The complex shear modulus and phase angle provide a measurement of the deformetion resistance of asphalt binders and are used to grade asphalt binders in accordance with AASHTO M320 and ASTEM6373.

2.10.1. Complex modulus and Phase angle

The complex shear modulus (G*) is defined as the ratio of the peak stress to the peak strain which measure the overall resistance to deformation of a material when repeatedly sheared, while the phase angle (δ) is the phase difference between the applied stress and the resulting strain. It represents the relative distribution between the elastic response and the viscous response to loading of the asphalt binder. The binder considered as purely viscous if the δ equal to 90° and as an ideal elastic solid if the δ equal to 0°.There are numerous studies for using the rheological techniques to predict pavement performance based on the main two rheological parameter complex shear modulus and phase.

G* is the ratio of maximum shear stress (τ max) to maximum shear strain (γ max). The time lag between the applied stress and the resulting strain is the phase angle δ. For a perfectly elastic material, the phase angle, δ, is zero, and all of the deformation is temporary. For a viscous material (such as hot asphalt), the phase angle approaches 90 degrees, and all of the deformation is permanent. In the DSR, a visco-elastic material such as asphalt at normal service temperatures displays a stress-strain response between the two extremes, as shown below.

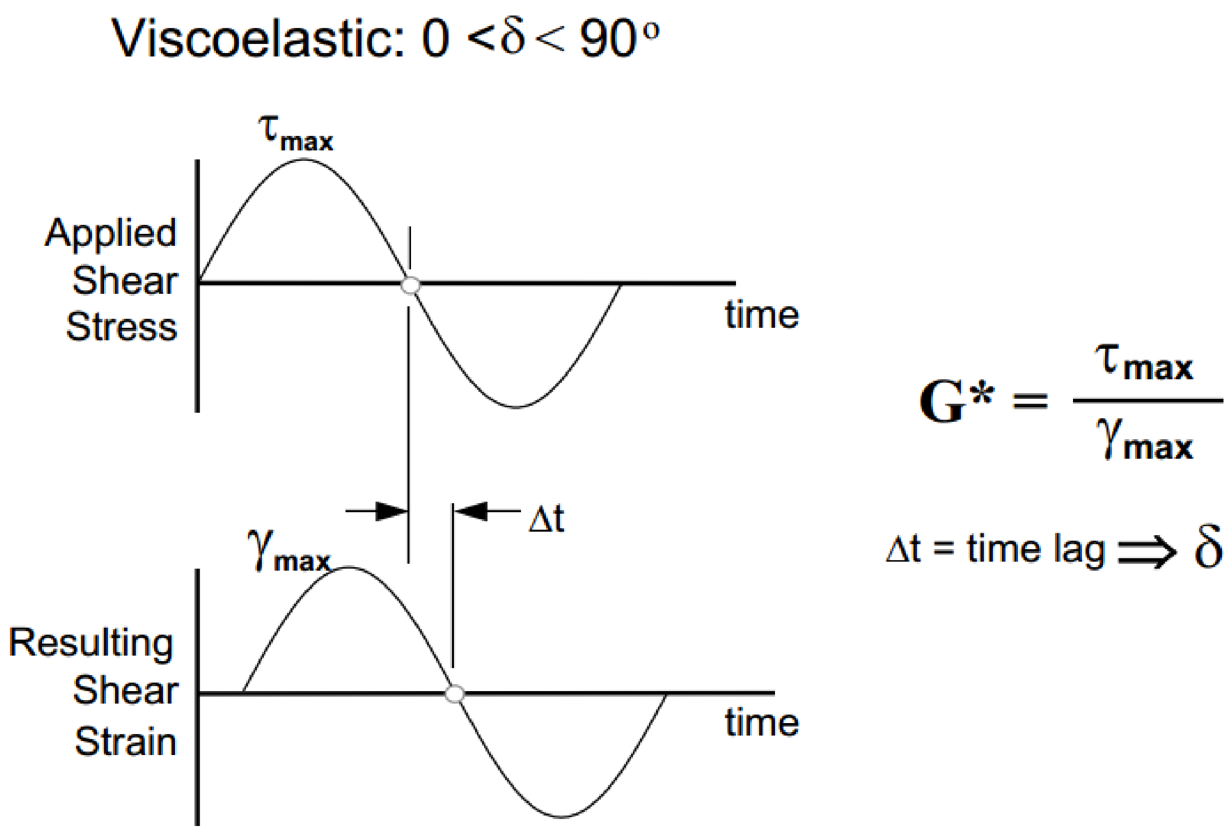


Figure 2.1. Strain Response of a Viscoelastic Material (Thomas G. Mezger, 2014)

2.10.2. PG Binders

The Performance Grade (PG) system is the method of categorizing an asphalt cement binder used in asphalt pavement relative to its rated performance at different temperatures. It was originally developed during the Strategic Highway Research Program (SHRP) in the early 1990's and was called "Super Pave." Performance grading is based on the concept that asphalt binder properties should be related to the conditions under which the binder is used including air and pavement temperatures, and specific application for that specific facility. The physical properties of asphalt cement change with temperature, i.e. asphalt cement is stiffer at lower temperatures and relatively softer at higher temperatures. PG asphalt binders are categorized and selected to meet performance criteria at expected high and low temperature extremes with a certain level of reliability. This increases the resistance to permanent deformation or rutting at high temperatures and increases the resistance to transverse thermal cracking at low temperatures (Minnesota Asphalt Pavement Association, 2010).

2.10.3. MSCR TEST

The material response in the MSCR test is significantly different from the response in the existing PG tests. In the PG system, the high temperature parameter, $G^*/\sin\delta$, is measured by applying an oscillating load to the binder at very low strain. Due to the low strain level, the PG high temperature parameter does not accurately represent the ability of polymer-modified binders to resist rutting. In the MSCR test, higher levels of stress and strain are applied to the binder, better representing what occurs in an actual pavement. By using the higher levels of stress and strain in the MSCR test, the response of the asphalt binder captures not only the stiffening effects of the polymer, but also the delayed elastic effects (where the binder behaves like a rubber band).The MSCR test uses the well-established creep and recovery test concept to evaluate the binder's potential for permanent deformation. Using the Dynamic Shear Rheometer (DSR), the same piece of equipment used today in the existing PG specification, one-second creep load is applied to the asphalt binder sample. After the 1-second load is removed, the sample is allowed to recover for 9 seconds. The test is started with the application of a low stress (0.1 kPa) for 10 creep/recovery cycles then the stress in increased to 3.2 kPa and repeated for an additional 10 cycles (Andrew Hanz, 2015).

2.10.3.1. How does the MSCR test work?

The MSCR test uses the Dynamic Shear Rheometer (DSR) to measure the non–recoverable creep compliance (Jnr) and percent recovery (PR). The asphalt binder sample is sandwiched between the DSR's parallel plates and is sheared for one second and allowed to recover without loading for nine seconds. J (compliance) is inversely related to complex modulus. The lower the Jnr value the stiffer the binder. The permanent strain measured directly relates to rutting. The calculated Jnr is unrecoverable strain/ applied stress. Thepercent recovery, which gives us information about binder modification, is recoverable strain/unrecoverable strain x 100%. Recovery tells us how readily the sample will return to its original shape after being subjected to a load or stress (FHWA, HIF, 2011).

2.11. Marshall Mix Design

This test procedure is used in designing and evaluating bituminous paving mixes and is extensively used in routine test program for the paving jobs. There are two major features of the Marshall method of designing mixes namely, density–voids analysis and stability-flow test. Strength is measured in terms of the 'Marshall's Stability' of the mix following the specification

ASTM D 1559 (2004), which is defined as the maximum load carried by a compacted specimen at a standard test temperature of 60°C. In this test, compressive loading was applied on the specimen at the rate of 50.8 mm/min until it was broken. The temperature 60°C represents the weakest condition for a bituminous pavement. The flexibility is measured in terms of the ‘flow value’ which is measured by the change in diameter of the sample in the direction of load application between the start of loading and at the time of maximum load. During the loading, an attached dial gauge measures the specimen's plastic flow (deformation) due to the loading. The associated plastic flow of specimen at material failure is called flow value. The density- voids analysis is done using the volumetric properties of the mix (Thomas W.Kennedy, 1996).

2.11.1. Marshall Stability and Flow

Marshall Stability and flow are bituminous mixture characteristics determined from tests of compacted specimens of a specified geometry. Typically, Marshall Stability is the peak resistance load obtained during a constant rate of deformation loading sequence. However, depending on the composition and behavior of the mixture, a less defined type of failure has been observed. Marshall Flow is a measure of deformation (elastic plus plastic) of the bituminous mix determined during the stability test. In both types of failure, the Marshall flow is the total sample deformation from the point where the projected tangent of the linear part of the curve intersects the *x*-axis (deformation) to the point where the curve starts to become horizontal. Marshall Stability and flow test results should consist of the average of a minimum of three specimens at each increment of binder content where the binder content varies in one-half percent increments over a range of binder content. The binder content range is generally selected based on experience and historical testing data of the component materials, but may involve trial and error to include the desirable range of mix properties. Dense-graded mixtures will generally show a peak in stability within the range of binder contents tested. Stability, flow, density, air voids, and voids filled with asphalt binder, may be plotted against binder content to allow selection of optimum binder content for the mixture. (ASTM D6927 – 05) (Airey, G., 1997).

Flow Determination for Two Types of Specimen Failure (ASTM D6927 – 05) Premature rutting of heavy duty hot mix asphalt (HMA) pavements has been a significant problem in recent years. High tire pressures and increased wheel loads are believed to be the primary causes of this phenomenon. Although the HMA has served reasonably well in the past, there is a need to reexamine its design to withstand the increased stress.

Chapter Three: Methodology and Experimental Work

3.1. Methodology

This research focuses on the use of recycle waste tire as a partial replacement of bitumen binder and compared the performance of the ordinary bitumen binder with bitumen partially replaced by waste tire. The ordinary binder used to this research is 60/70 penetration grade because mostly used in our country obtained from Addis Ababa Institute of Technology civil engineering department and IFH Engineering laboratory.

Different types of test have been performed to know about the Waste Tire meets the common specification limit of the binder. Test performed include amplitude sweep test, frequency sweep test, performance grade, multiple stress creep recovery, ductility, penetration, softening point, flash point and Marshall Mix Design.

In order to prepared Waste Tire for a binder material two types of process are there: the dry and wet processes. In the wet process, Waste Tire acts as an asphalt cement modifier while in dry process Waste Tire acts as a portion of fine aggregates. The main goal of this research is to determine the use of Waste Tire as a partial replacement of bitumen binder therefore wet process was used.

The partial replacement of bitumen binder were prepared by mixing 10%, 20%, 25% and 30% by weight of recycled Waste Tire with ordinary bitumen binder for DSR test. Quality tests conducted ductility, softening point, penetration, flash point and mass loss on heat in RTFO. These tests measures the asphalt binder only at one temperature which do not give any indication how the material will perform at the different ranges of temperatures and also they do not relate directly to asphalt binder performance of pavements in actual condition. However, there are other tests, which can better relate the actual performance of the binder. This is the performance grade of asphalt binder, which can measure the physical properties of the binder material in different temperature ranges. The performance based tests were performed by using Dynamic Shear Rheometer (DSR)test. These tests conducted using MADVEL BOHLIN INSTRUMENT to analyze the rheological properties, aging effect and rutting performance of original bitumen and bitumen mixed with Waste Tire. Both binders prepared for Dynamic Shear Rheometer test based on AASHTO T31510.

3.1.1. Preparation of Waste Tire

First the collected waste tire were cut into small pieces leaving the part that has fiber and wire, then properly wash it and expose it to sun light until it dried well. After that, the parts of the dried tire were grinded into powder using SJP machine in Addis Ababa University, Mechanical department laboratory. When there were any mix of fiber and wire immediately excluded from the sample.

3.1.2. Properties of Binder

In this study bitumen 60/70 penetration grade was used in the preparation of modified binder as it is widely used and acceptable for high temperature zone. It is subjected to quality tests in the laboratory to determine its physical properties. These tests includes

- Penetration (AASHTO T 49)
- Ductility (AASHTO T 51)
- Softening point (ASTMD36-2002)
- Flash point (ASTM D92)
- RTFO Mass loss on heat (AASHTO T240-97)

3.1.3Binder Preparation

Four different percentage of Waste Tire were used to replace bitumen binder. The Percentages used for in this study were 10%, 20%, 25% and 30% of Waste Tire by weight. Original binder heated until it becomes fluid to mix with each percentage of the Waste Tire. The mix temperature was 180C^{o} for 60 minutes until it become easy to mix with. After finishing, the sample preparation stayed at room temperature to be cooled.

3.1.4. Binder Test

Three performance-measuring methods were conducted. The first performance measuring techniques used was super pave system using an oscillatory instrument known as Dynamic Shear Rheometer (DSR), the second Marshal Mix Design and the third one is that conventional performance measuring techniques these are penetration, softening point, ductility and flash point.

3.1.5. Conventional Test

Ductility Test Many asphalt-paving technologists consider ductility as an important property of asphalt cement. It runs in accordance with ASTM D113, measure the distance in centimeters that standard briquettes of asphalt cementwill stretchbefore breaking. The test sample is brought to temperature in a water bath, which is maintained at the standard temperature of 25 C^o. The two ends of the sample are separated at the rate of 5cm/minute until rupture. The water must be at the same specific gravity as the asphalt to prevent floating or sinking of the stretched sample.

Penetration test is an empirical test used to measure the consistence of asphalt cement. Usually penetration is measured at 25C^o which usually also approximates average service temperature of the HMA pavement. The sample is placed under a needle or prescribed dimensions. The needle is loaded with a 100g weight and is allowed to penetrate the asphalt cement sample for 5 seconds. The depth of penetration is measured in units of 0.1mm and is reported as penetration units. This test is done according to ASTM D5.

Softening Point is measured by ring and ball method in accordance with ASTM D36. It can simply be defined as the temperature at which asphalt cement cannot support the weight of a steel ball and starts flowing. Its purpose is to determine the temperature at which a phase change occurs in the asphalt cement. The test consists of taking a brass ring filled with asphalt cement and suspending it in a beaker filled with water. A steel ball of specified dimensions and weight is placed in the center of the sample. The bath is heated at a controlled rate of 5C^o / minute. When the asphalt cement softens, the ball and asphalt cement sink towards the bottom of the breaker. The temperature is recorded at the instant when the softened asphalt cement sinks the prescribed distance and touches the bottom plate. The test is conducted with duplicate specimens. If the difference between the two temperatures exceeds 2F^o, the test must be repeated.

Flash point and fire point

Taken as the temperature read on the thermometer at the time of the flame application that causes a bright flash in the interior of the cup in closed system. For open cup it is the instance when flash appears first at any point on the surface of the material. The heating is continued until the volatiles ignite and the material continues to burn for 5 seconds. The temperature of the sample material when this occurs is recorded as the fire point.

3.1.5. Rolling Thin Film Oven (AASHTO T 240)

The rolling thin film oven (RTFO) aging procedure is a conditioning step that simulates construction aging of asphalt binders. The RTFO (Figure3-1) consists of an oven chamber with a vertical circular carriage. Sample bottles rest in the carriage and the assembly rotates about the carriage center. A fan circulates air in the chamber. At the bottom of the rotation, an air jet blows hot air into the sample bottle. 35 ± 0.5 g of asphalt binder is poured in each bottle and then placed in the carriage and rotated at a rate of 15rev/min. The airflow is set at a rate of 4000 ml/min, and the samples are subjected to these conditions for 85 min. The conditions in the test are not exactly as found in the field but experience has shown that the amount of hardening in the RTFO test correlates reasonably well with that observed in a conventional batch mixer (Prowell, B. D., 2005)**.**

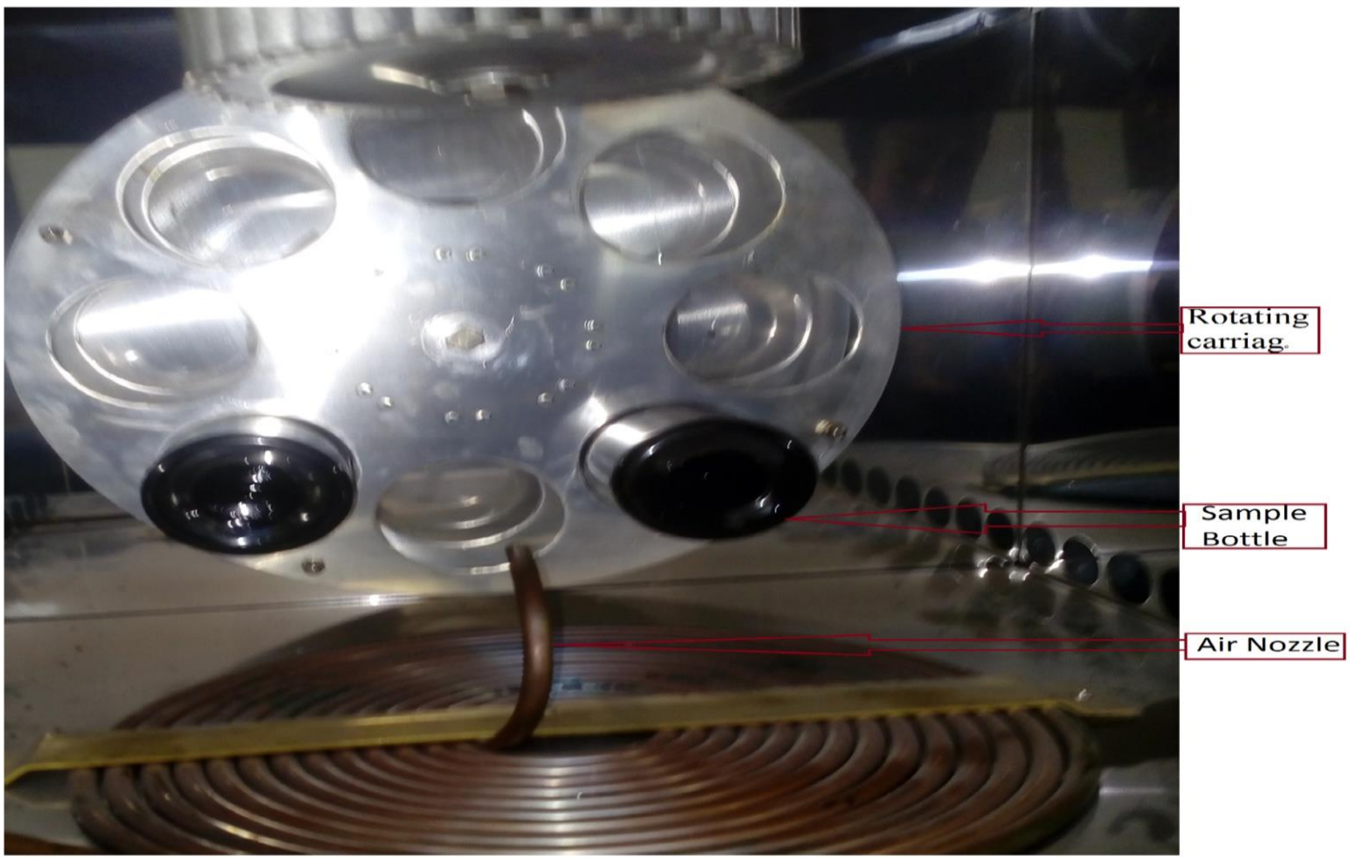


Figure 3.1. Rolling Thin Film Oven

Figure 3.2. RTFO Test Sample

The RTFO test determines the mass change due to heat from the binder during the test. Mass change is an indication of the aging that may occur in the asphalt during mixing and construction operations. Mass loss is reported as the average percent loss of two samples after RTFO aging and before RTFO is calculated using the following equation:

$$Mass\ change\ \% = \frac{Original\ mass - aged\ mass}{original\ mass} x100$$

3.1.6. Dynamic Shear Rheometer (AASHTO TP5)

This test is used to measure the linear viscoelastic modulus of asphalt binders in a sinusoidal loading mode. Measurements may be obtained at different temperatures, strain and stress levels, and test frequencies. The test operation is that; asphalt binder is sandwiched between two parallel plates, one that is fixed and the other one is that oscillates. As the plate oscillates, the sample is subjected to a defined strain or stress that is resisted by the material through its complex shear modulus (G*). The complex shear modulus (G*) is a measure of the total resistance of a material to deformation when exposed to repeated pulses of shear stress (Asphalt Institute, 1997).

The DSR measures a specimen's complex shear modulus (G*) and phase angle (δ) over a temperature range from 30°C to 80°C. The complex shear modulus (G*) is defined as the ratio of the peak stress to the peak strain which measure the overall resistance to deformation of a material when repeatedly sheared, while the phase angle (δ) is the phase difference between the applied stress and the resulting strain. It represents the relative distribution between the elastic response and the viscous response to loading of the asphalt binder. The binder considered as purely viscous if the δ equal to 90° and as an ideal elastic solid if the δ equal to 0°. A lower value of complex shear modulus G* means that the asphalt is softer, and it can deform without developing large stresses. In addition binders with high complex shear modulus G* may reduce rutting problems in the asphalt. In order to resist rutting, an asphalt binder should be stiff enough and sufficiently elastic (able to return to its original shape after load deformation).Therefore, higher complex shear modulus elastic portion, G*/sin δ, would be an advantage.

The dynamic shear rheometer (DSR) test is used to characterize the visco-elastic behavior of asphalt binders at medium to high temperatures. In this test, a thin asphalt binder sample sandwiched between two circular plates. The lower plate is fixed while the upper plate oscillates back and forth across the sample at 10 rad/sec to create a shearing action. The specified oscillation rate of 10 rad/sec is meant to simulate the shearing action corresponding to a traffic speed of about 55 mph (90 km/hr.). The test is largely software controlled (A. S. M. Ashek Rana, 2004).

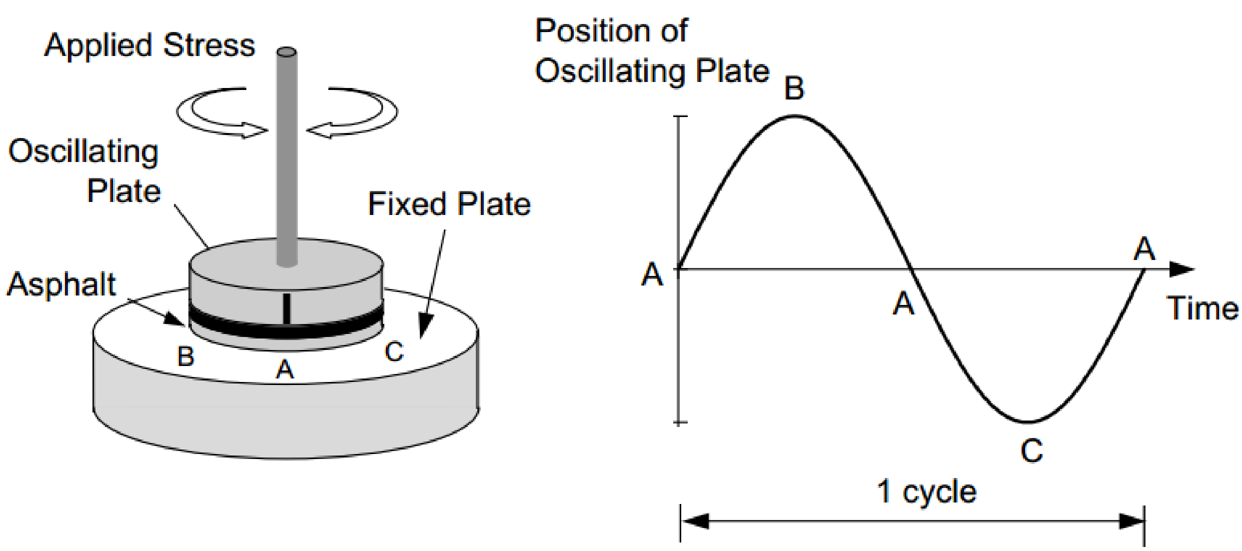


Figure 3.3. Schematic Configuration and Loading Mode of DSR (Arashotamed, & Izadi, 1950)

3.1.6.1. Test procedure

For operation using parallel plates, follow Section 10 of AASHTO Designation: TP5. The procedure when using a cup and stepped disc is to pour the heated binder into a sample cup such that the meniscus is above the rim of the cup. Let the cup cool at room temperature for 15 min. Heat a clean broad-blade, straightedge spatula on a hot plate. Trim the excess binder above the top of the cup using the hot blade. The number of repetitions of heating/trimming will vary depending on the stiffness of the binder. Usually two to four repetitions of cleaning/heating/trimming are necessary for one pass. When one complete pass has been accomplished, the surface should be smoothed with a final single stroke pass. Remove the excess binder of from the fixed plate surface surrounding using “Stracho”. When the holder is clean, push the cup up out of the holder.

3.2. Experimental Work

Accordingly, four main types of tests were conducted using DSR in this research to determine the binder properties. This are-

I. Amplitude Sweep Test (AST):- During amplitude, sweep test frequency is kept constant while the amplitude of the deformation is varied. Amplitude sweeps test are mainly used to determine the linear-viscoelastic range of the bitumen (modified or unmodified bitumen). Using a frequency of 10 rad/sec was applied. The test was performed at four different temperatures $10C^0$ $21.1C^0$and $37.8C^0$using 8mm diameter plate size and 2mm gap and for $54.4C^0$using 25mm diameter plate size and 1mm gap. The dynamic rheological properties were tested by measuring the required shear stress to achieve a preset strain level for both aged and unaged mixes. The strain level should be large enough so that it is measurable and small enough so that the required stress does not exceed the capacity of the testing device or damage the sample. The controlled stress level for AST was from 100Pa to 10MPa.The complex shear modulus G* versus strain plot used to determine the linear viscoelastic region.

II. Frequency Sweep Test (FST):- In general, frequency sweep test results are used for the construction of the so-called “Master curves” which are able to estimate the rheological properties of asphalt mastics and mixtures (JP Wu, PR Herrington and K Neaylon, 2015). During the frequency sweep test the frequency is varied while the amplitude of the deformation or alternatively the amplitude of the shear stress is kept constant. DSR frequency sweep tests are designed to construct master curves of binder complex shear modulus (G*) and phase angle (δ). The master curves characterize binder rheological properties over a wide range of temperature or frequency. The master curves can be used to estimate binder G* and δ values at any interested temperature and frequency.

The higher the G* value, the stiffer and thus the more resistant to rutting the asphalt binder, and implicitly the mix, will be. The lower the δ value, the more elastic the asphalt binder (mastic), knowing that an increased elasticity makes the asphalt binder more resistant to permanent deformation. It has been found out that the rutting susceptibility should decrease with the increasing of the G*/sinδ values, thus the Super pave parameter is intended to control rutting by controlling the total energy dissipated per cycle. As seen from the graphs in chapter four, complex shear modulus (stiffness) values have increased with the increase in frequency, while they decreased with the increase of the temperature.

In this study, frequency sweep tests were also performed on the same temperatures as AST. The shear strain applied was 1% for all the samples, i.e. 0%, 10%, 20%, 25% and 30% the frequency range used was 0.1Hz to 25Hz. The highest loading frequency was selected because it is intended to simulate highway traffic speeds, and the lowest testing frequency was selected because it simulates loading in slow moving traffic conditions.

All of these values vary for each binder type. As for the temperature shift factors, a 21.1 is zero for all the binder types because all the parameters are shifted to 21.1C^o, the shift factor for 10.0 C^o positive and for a 37.8 C^o and a 54.4 C^o the values are negative because the stiffness parameters are shifted to reduced temperature which is 21.1C^o.

III. PG grade: - During the PG grade determination the frequency is varied while the amplitude of the deformation or alternatively the amplitude of the shear stress is kept constant. PG grade determination tests are designed to know performance grade of the binder (i.e. higher temperature grade which is the maximum pavement service temperature). This higher temperature is used for MSCR test.

In this study, PG grade determination tests were performed on unaged and aged samples. The tests were performed on higher temperature using 25mm parallel plate and 1mm gap. The starting temperature was decided based on bitumen type and test started from expected lower temperature grade, increasing until it achieves pass-fail temperature.

IV. Multiple Stress Creep Recovery (MSCR) Test

The Multiple Stress Creep Recovery (MSCR) test is the latest improvement to the Super pave Performance Graded (PG) Asphalt Binder specification. This new test and specification listed as AASHTO T350 and AASHTO M332 provide the user with a new high temperature binder specification that more accurately indicates the rutting performance of the asphalt binder and is blind to binder modification. A major benefit of the new MSCR test is that it eliminates the need to run tests such as elastic recovery and phase angle procedures designed specifically to indicate polymer modification of asphalt binders. Several studies have shown that the $G^*/\sin(\delta)$ based specification does not correlate well with field performance (Arashotamed, Amit Bhasin & Anoosha Izadi, 1950).

The test protocol (AASHTO T350) requires that a 25-mm diameter and 1-mm thick asphalt specimen is subjected to 10 cycles of one second creep loading followed by 9 seconds recovery period at stress levels of o.1Kpa and 3.2Kpa at the high PG temperature using a DSR. In this way 22 cycles at the 0.1-kPa stress level followed by 11 cycles at the 3.2-kPa stress level for 33 cycles would have been done. The first 11 cycles at 0.1 Kpawould have been used for conditioning the specimen. There are no rest periods between creep and recovery cycles or changes in stress level. The total time required for completing the two-step creep and recovery test is 330s. From the test we can determine the following main parameters,

i. Non-recoverable creep compliance

ii. Average percent recovery

iii. Percent difference in recovery

3.3. Marshall Methods of Mix Design

Asphalt mixes are used in the surface layer of road and airfield pavements. The mix is composed usually of aggregate and asphalt cements. Some types of bituminous mixes are also used in base course. The design of asphalt paving mix, as with the design of other engineering materials is largely a matter of selecting and proportioning constituent materials to obtain the desired properties in the finished pavement structure.

In the Marshall Test method of mix design, three compacted samples are prepared for each binder contents. Four binder contents are to be tested to get the optimum binder content. All the compacted specimens are subject to the following tests:

· Bulk density determination.

· Stability and flow test.

· Density and voids analysis.

Stability test

In conducting the stability test, the specimen is immersed in a bath of water at a temperature of 60° ± 1°C for a period of 30 minutes. It is then placed in the Marshall Stability testing machine and loaded at a constant rate of deformation of 5 mm per minute until failure. The total maximum in kN is taken as Marshall Stability. The stability value so obtained is corrected for volume. The total amount of deformation is units of 0.25 mm that occurs at maximum load is recorded as Flow Value. The total time between removing the specimen from the bath and completion of the test should not exceed 30 seconds (Asphalt Institute MS-2, No.2).

3.3.1. Optimum Bitumen Content

To determine the optimum bitumen content, 15 samples each of 1200 gm in weight were prepared using five different bitumen contents i.e. three samples for one- bitumen content to have an average value. First, the aggregates were heated to a temperature of 175ºC to 190ºCthe compaction mold assembly and rammer were cleaned and kept pre-heated to a temperature of 100ºC to 145ºC. The bitumen was also heated to a temperature of 135-170ºC and the required amount of first trial of bitumen was added to the heated aggregate and thoroughly mixed. The mix was placed in a mold and compacted with 75 numbers of blows both sides. The sample is taken out of the mold after minimum of an hour using sample extractor.

Marshall Properties of the asphalt mix such as stability, flow, density and volumetric properties were obtained for various bitumen contents. Then the following parameters used to draw graphs were utilized in order to determine the optimum bitumen content for the mixture.

- Stability vs. Bitumen Content
- Flow vs. Bitumen Content
- Bulk Specific Gravity vs. bitumen Content
- Air voids (Va) vs. Bitumen Content
- Voids in mineral aggregates vs. bitumen Content
- Voids Filled with Bitumen (VFB) vs. Bitumen Content

According to Asphalt Institute the optimum bitumen content (OBC) for proposed mix is the average of three values of bitumen content i.e. bitumen content at the highest stability, bitumen content at the highest value of bulk density and bitumen content at 4% and less of air voids. Then properties of the asphalt mix using optimum bitumen content such as stability, flow, bulk density and volumetric properties (i.e. VA, VMA and VFA) are obtained and checked against specifications range.

3.3.1.1. Volumetric Properties of HMA Mixes

The volumetric properties of HMA mixes are air voids, voids in mineral aggregates and void filled with asphalt. These properties indicate the performance of the mixes in the field. The volumetric component diagram of HMA is shown in Figure below.

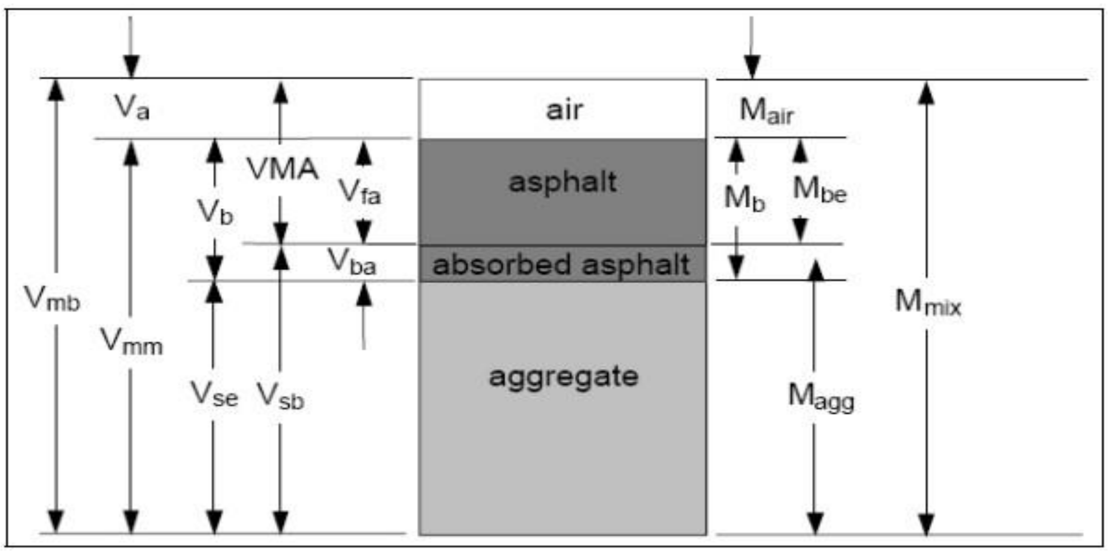


Figure 3.4. Mass and volume relationships in asphalt mixtures (FHWA Super pave, 1995)

All the components are defined in the following:

VMA = Volume of voids in mineral aggregate

V_{mb} = Bulk volume of compacted mix

V_{mm} = Void less volume of paving mix

V_{fa} (VFA) = Volume of voids filled with asphalt

V_a = Volume of air voids

V_b = Volume of asphalt binder

V_{ba} = Volume of absorbed asphalt binder

V_{sb} = Volume of mineral aggregate (by bulk specific gravity)

V_{se} = Volume of mineral aggregate (by effective specific gravity)

M = Total mass of asphalt mixture

M_{be} = Mass of effective asphalt binder

M_{agg} = Mass of aggregate

M_{air} = Mass of air = 0

M_b = Mass of asphalt binder

For many years, three other volumetric parameters Va, VMA, and VFA, have been widely used and at various times have formed critical design thresholds.

They are:

- ✓ **Percent Air Voids in compacted Mixture: -**The small air spaces between the coated aggregate particles in the total compacted paving mixture are called air voids. It can be determined by using the equation below.

$$\mathrm{Va} = 100 * \frac{Gmm - Gmb}{Gmm}$$

Where, Va = Air voids in compacted mixture, percent of total volume, Gmm= maximum specific gravity of paving mixture, Gmb= bulk specific gravity of compacted mixture

- ✓ **Percent VMA in compacted Paving Mixture: -**It is intergranular void space between the aggregate particles in a compacted paving mixture. It includes the air voids and the effective asphalt content, expressed as a percent of the total volume. The objective is to furnish enough space for asphalt binder so as to provide adequate adhesion required to bind the aggregate. It is calculated as

$$\mathrm{VMA} = 100 - \frac{\mathrm{Gmb} * \mathrm{Ps}}{Gsb}$$

Where, VMA = voids in the mineral aggregate, percent of the bulk volume, Gsb= bulk specific gravity of total aggregate, Gmb = bulk specific gravity of the compacted mixture, Ps = aggregate content, percent by mass of total mixture

- ✓ **Percent VFA in Compacted Mixture: -**The percentage of the voids in mineral aggregates that contain asphalt and not the absorbed asphalt is called Voids filled with asphalt (VFA). It is determined as

$$VFA = \frac{100(VMA - Va)}{VMA}$$

Where, VFA = Voids filled with asphalt, percent of VMA, VMA = Voids in mineral aggregates, percent of the bulk volume, Va = Air voids in compacted mixture, percent of total volume.

Aggregate graduation Requirement

The coarse and fine aggregate particles were separate into different sieve size and proportioned to obtain the desired gradation for bituminous mixtures of ASTM 3515 for 19mm nominal maximum aggregate size. The aggregate particle size distribution that would be used for the preparation of mixtures is shown in Table 3.1

Table **3**.1. Aggregates graduation requirement based on ASTM D3515

SIEVE SIZE		**25**	19. 0	12. 5	9. 5	4. 75	2. 36	1. 18	0. 60	0. 30	0. 15	0. 0 75
14--25mm		100	76.3	7.5	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1
6--14mm		100	100	98.8	77.7	6.9	1.1	0.7	0.6	0.6	0.6	0.6
3--6mm		100	100	100	99.5	89.3	18.0	10. 1	7.9	6.1	6.1	6.1
0--3mm		100	100	100	99.6	99.2	95.0	64. 3	44. 8	29.4	19.9	11. 2
Filler		100	100	100	100	100	100	100	100	100	99.3	96. 9
		100	100	100	100	100	100	100	100	100	100	10 0

SIEVE SIZE	Blending (%)	**25**	**19. 0**	**12. 5**	**9. 5**	**4. 75**	**2. 36**	**1. 18**	**0. 60**	**0. 30**	**0. 15**	**0. 0 75**
14--25mm	**25. 0**	25. 0	19. 1	1. 9	0. 1	0. 0	0. 0	0. 0	0. 0	0. 0	0. 0	0. 0
6--14mm	**24. 0**	24. 0	24. 0	23. 7	18. 6	1. 7	0. 3	0. 2	0. 1	0. 1	0. 1	0. 1
3--6mm	**8. 0**	8. 0	8. 0	8. 0	8. 0	7. 1	1. 4	0. 8	0. 6	0. 5	0. 5	0. 5
0--3mm	**41. 0**	41. 0	41. 0	41. 0	40. 8	40. 7	38. 9	26. 4	18. 4	12. 0	8. 1	4. 6
Filler	**2. 0**	2. 0	2. 0	2. 0	2. 0	2. 0	2. 0	2. 0	2. 0	2. 0	2. 0	2. 0
0	**0. 0**	**0. 0**	**0. 0**	**0. 0**	**0. 0**	**0. 0**	**0. 0**	**0. 0**	**0. 0**	**0. 0**	**0. 0**	**0. 0**
Total	100	100	94. 1	76. 6	69. 5	51. 5	42. 7	29. 4	21. 1	14. 7	10. 8	7. 3

SIEVE SIZE		25	19	12. 5	9. 5	4. 75	2. 36	1. 18	0. 6	0. 3	0. 15	0. 0 75
Up (specification)		100.0	100 .0	84.0	76.0	60.0	48.0	38. 0	28. 0	20.0	15.0	10. 0
Down(specification)		100.0	85. 0	71.0	62.0	42.0	30.0	22. 0	16. 0	12.0	8.0	4.0
Middle range		**100**	**92.5**	**77.5**	**69.0**	**51.0**	**39.0**	**30.0**	**22.0**	**16.0**	**11.5**	**7.0**
Blended Grading		**100**	**94.1**	**76.6**	**69.5**	**51.5**	**42.7**	**29.4**	**21.1**	**14.7**	**10.8**	**7.3**
Up(TOLERANCE LIMITS)		**100**	**99.1**	**81.6**	**74.5**	**55.5**	**46.7**	**33.4**	**25.1**	**17.7**	**12.8**	**9.3**
Down(TOLERANCE LIMITS)		**100**	**89.1**	**71.6**	**64.5**	**47.5**	**38.7**	**25.4**	**17.1**	**11.7**	**8.8**	**5.3**

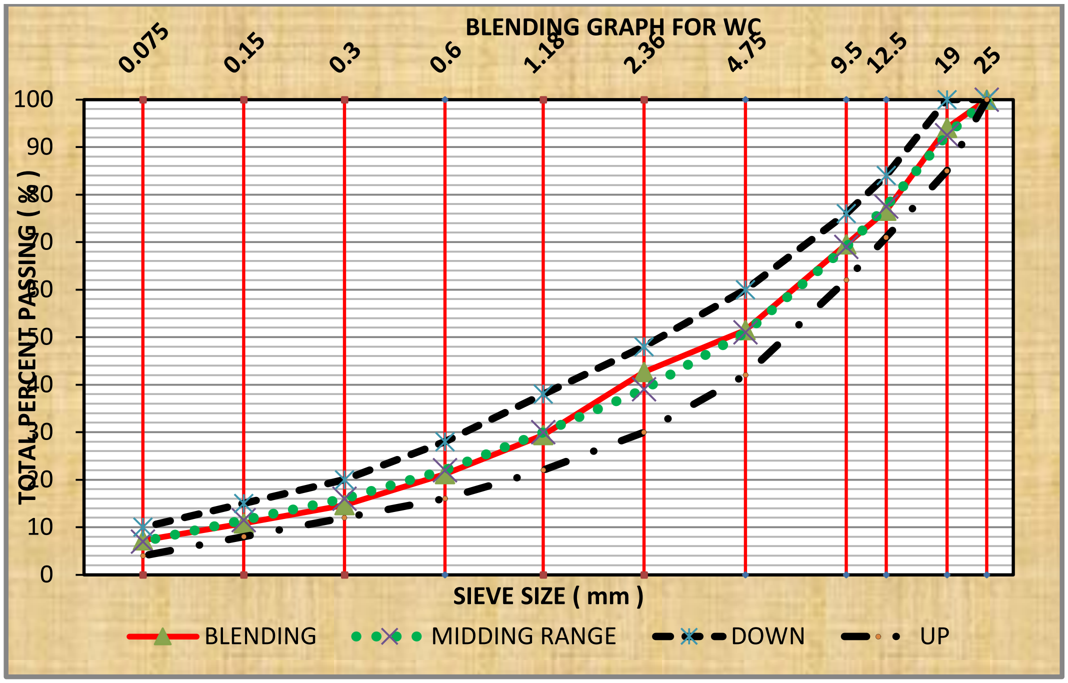


Figure 3.5. Aggregate gradation limit graph for ASTM Specification

3.3.1.2. Preparation of test specimens

The coarse aggregate, fine aggregate, and the filler material should be proportioned so as to fulfill the requirements of the relevant standards. The required quantity of the mix is taken so as to produce compacted bituminous mix specimens of thickness 63.5 mm approximately. 1200gm of aggregates and filler are required to produce the desired thickness. The aggregates are heated to a temperature of 170° to 180°C the compaction mold assembly and rammer are cleaned and kept pre-heated to a temperature of 100°C to 145°C. The bitumen is heated to a temperature of 130°C to 160°C and the required amount of first trial of bitumen is added to the heated aggregate and thoroughly mixed. The mix is placed in a mold and compacted with number of blows specified. The sample is taken out of the mold after few minutes using sample extractor.

Chapter Four: Results and Data Analysis

This chapter focuses on the laboratory results and discussions the performances of the asphalt concrete by using Waste Tire as a partial replacement of bitumen binder. The laboratory tests results help to concluded on the use of Waste Tire and fulfill the requirements of the common binder specification (AASHTO)

4.1. The effect of Waste Tire on conventional properties of Asphalt Binder

The control material, 60/70 penetration grade bitumen binder used to partially replace by Waste Tire and it was checked for its conformity by conducting conventional tests. In addition, the test results are represented as follows.

Table 4.1. Test Result vs. Specification Requirements of 60/70 Bitumen (ASTM D946)

Waste Tire contents	Test Type	Specification Requirement	Test Results
	Penetration (25C°) 100g,5sec.	60 - 70	62
	Ductility (25C°) 5cm/min.,cm, (Min.)	100	117
	Softening point (C°)	46-56	58.5
	Flash Point C° (Cleveland open cup Min.)	232	310
0%	Fire Point (C°)	-	350
	Penetration (25C°) 100g,5sec.	60 - 70	59
	Ductility (25C°) 5cm/min.,cm (Min.)	100	16.4
	Softening point (C°)	46-56	64
	Flash Point C° (Cleveland open cup Min.)	232	310
20%	Fire Point (C°)	-	350
	Penetration (25C°) 100g,5sec.	60 - 70	58
	Ductility (25C°) 5cm/min.,cm (Min.)	100	14.45
	Softening point	46-56	66
	Flash Point C° (Cleveland open cup Min.)	232	312
25%	Fire Point(C°)	-	350
	Penetration (25C°) 100g,5sec.	60 - 70	56
	Ductility (25C°) 5cm/min.,cm (Min.)	100	11.6
	Softening point (C°)	46-56	69.5
	Flash Point C° (Cleveland open cup Min.)	232	314
30%	Fire Point(C°)	-	350

4.1.1. The Effect of Waste Tire on Penetration

Figure 4-1 and Table 4-1represents the effect of variable concentrations of waste tire on the penetration properties of asphalt binder. From the graph below and table above, the addition of Waste Tire affected the penetration grade of bitumen binder. The addition of 20 % Waste Tire the penetration value of the binder decreases from 62mm to 59mm. Further increased the percentage of waste tire from 20% to 25% and 30%, the degree of penetration slightly decreases and the values become58mm and 56 respectively. From this observation we can predicts that the material will show further decrease in penetration value as Waste Tire percentage further increase due to the stiffness property of the waste tire that means it increases the rutting performance of the binder.

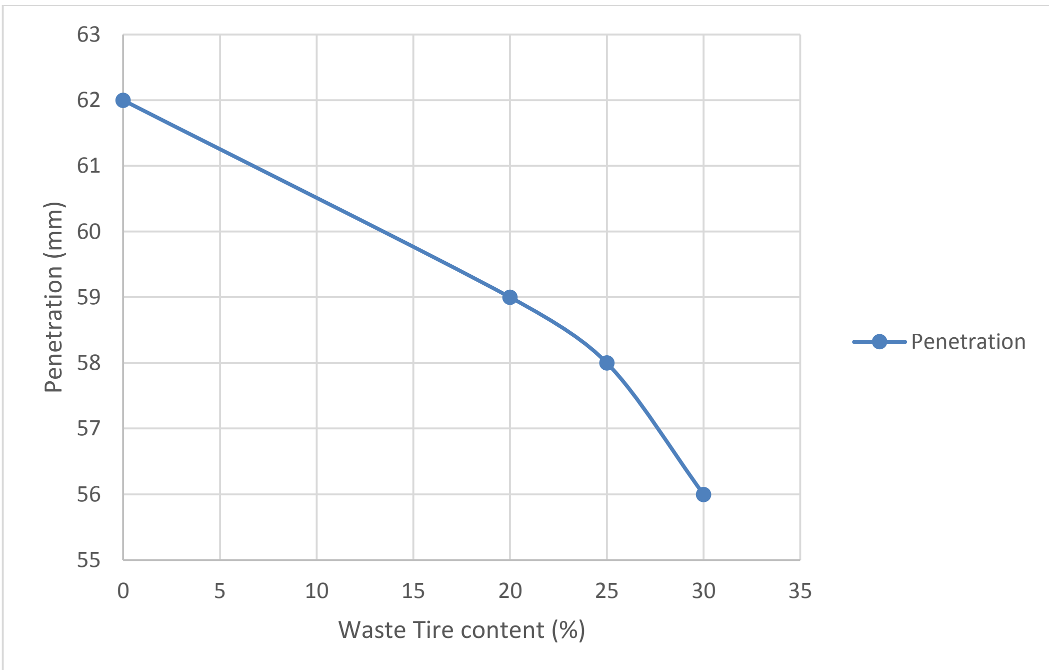
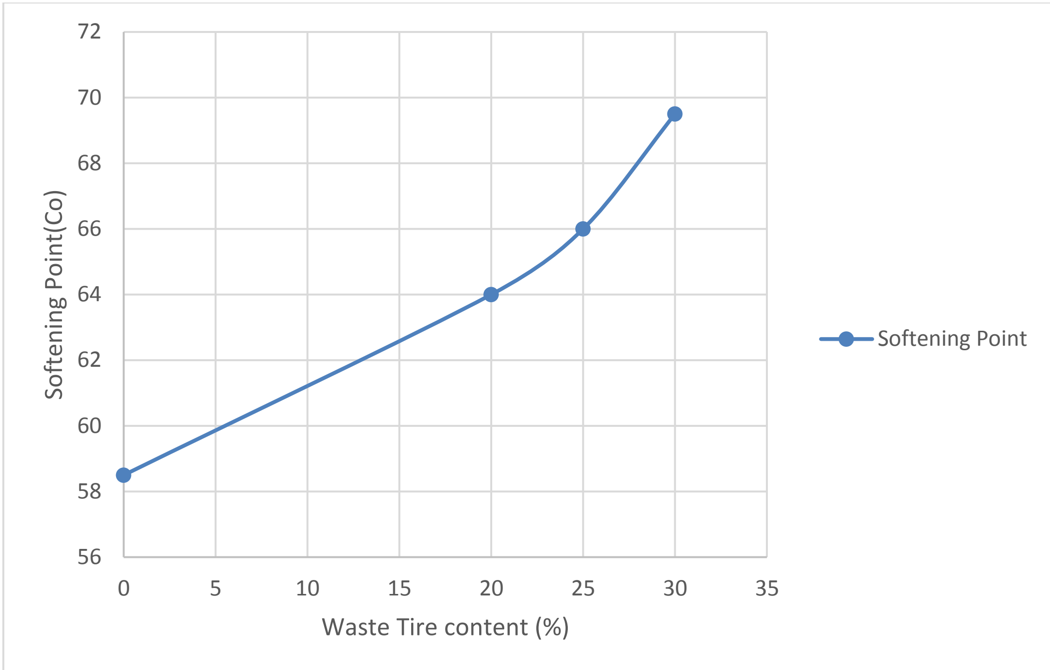


Figure 4.1.Penetration test result

4.1.2. The Effect of Waste Tire on Softening Point

From the Table 4-1 and Figure 4-2, it can be observed that addition of waste tire increase the softening point of the asphalt binder also increased. The decrease in softening point shows negative effect on the property of asphalt binder. From the table above and figure below when the waste tire content increases the softening point also increases which reflects in better rutting resistance at higher temperature.



5Figure 4.2. Softening point test result

4.1.3. The Effect of Waste Tire on Ductility

A summary of the average values of the ductility test is presented the Table 4-1 and Figure 4-3. The result of ductility test shows that when the addition of waste tire increases ductility values decrease because of the stiffness nature of the waste tire at low temperature implies that using waste tire at higher temperature is more preferable than low temperature.

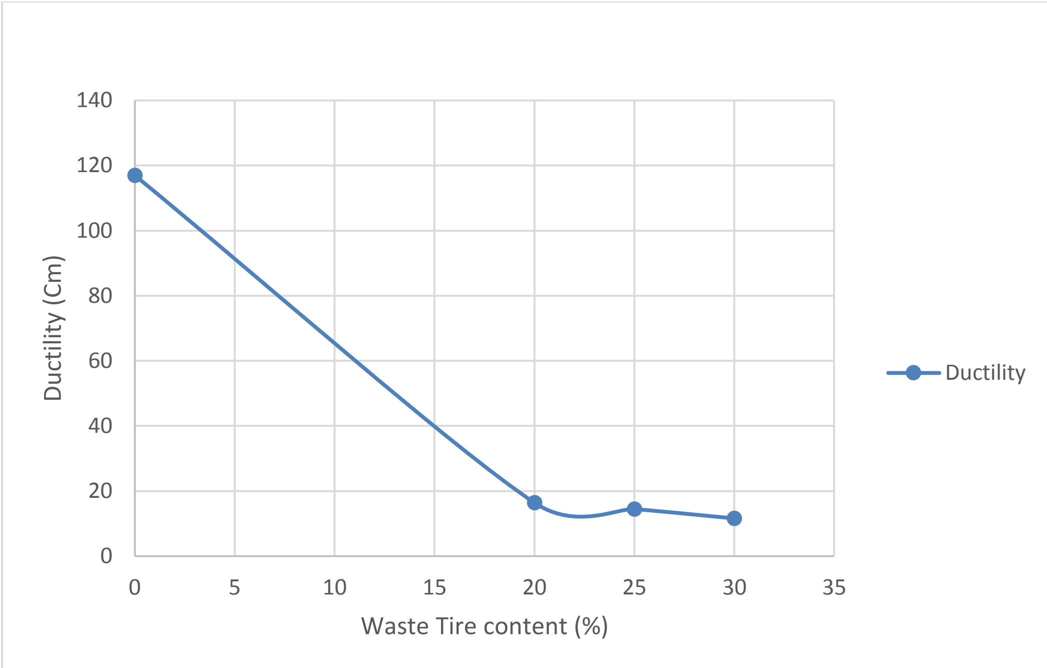


Figure 4.3. Ductility Test Result

4.1.4. The Effect of Waste Tire on Flash point and Fire Point

From the Table 4.1 and the Figure 4.4 both the flash point and the fire point is fulfilled the general requirements of the binder at which bitumen material left out volatiles and gets ignited & burn at the give temperature respectively.

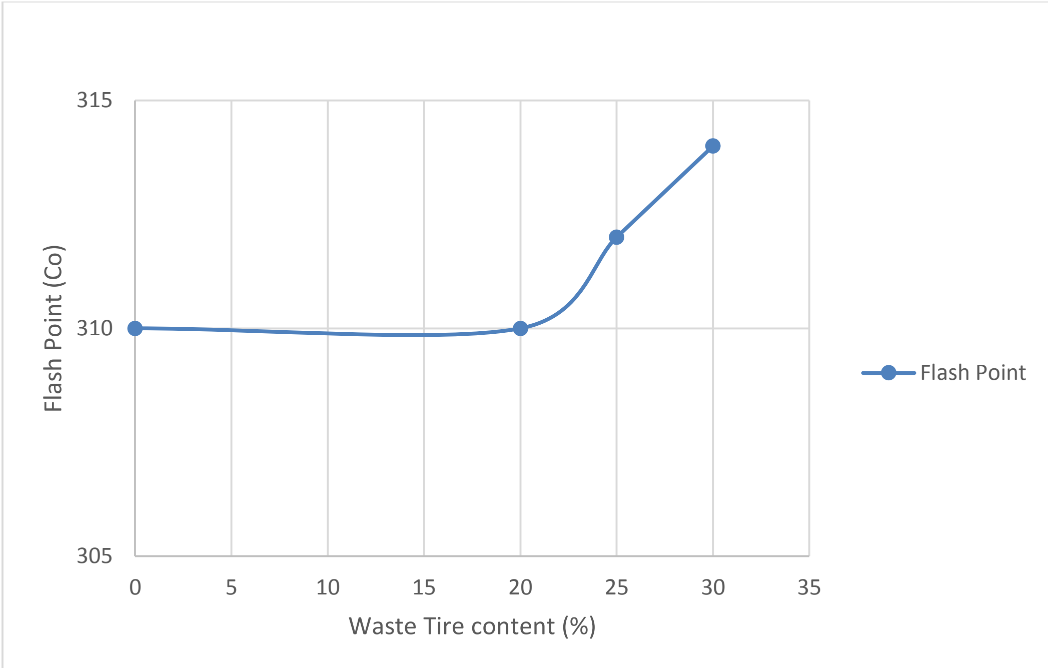


Figure 4.4. Flash point Test Result

4.1.5. The effect of Waste Tire on mass change (RTFO)

From the table below the result of RTFO test showed that as the Waste Tire content increases the mass change almost the same. According to the AASHTO specification the mass change is passed (i.e. the maximum mass loss on heat is 1%).

Table4.2. RTFO Mass Change

Waste Tire containing binder	Mass of sample +flax Before aging (g)	Mass of sample +flax After aging	Mass change (%)
10%	200	199	0.5
20%	192	191	0.52
25%	200	199	0.5
30%	192	191	0.52

4.2. The rheological properties of asphalt binder by adding waste tire on the bitumen.

4.2.1. The Effect of Waste Tire on Amplitude Sweep Test

Amplitude Sweep Test conducted by using DSR test to determine the linear viscoelastic range of the binder. The linear viscoelastic limits determined as the point beyond which the complex modulus at 95% of the measured value at zero-strain. The linear viscoelastic range was determined for all percentage binders in 10C^o, 21.1C^o, 37.8C^o and 54.4C^o. A typical LVER is determined for 25% of Waste Tire content at 21.1^{o}C (Figure 4-5).

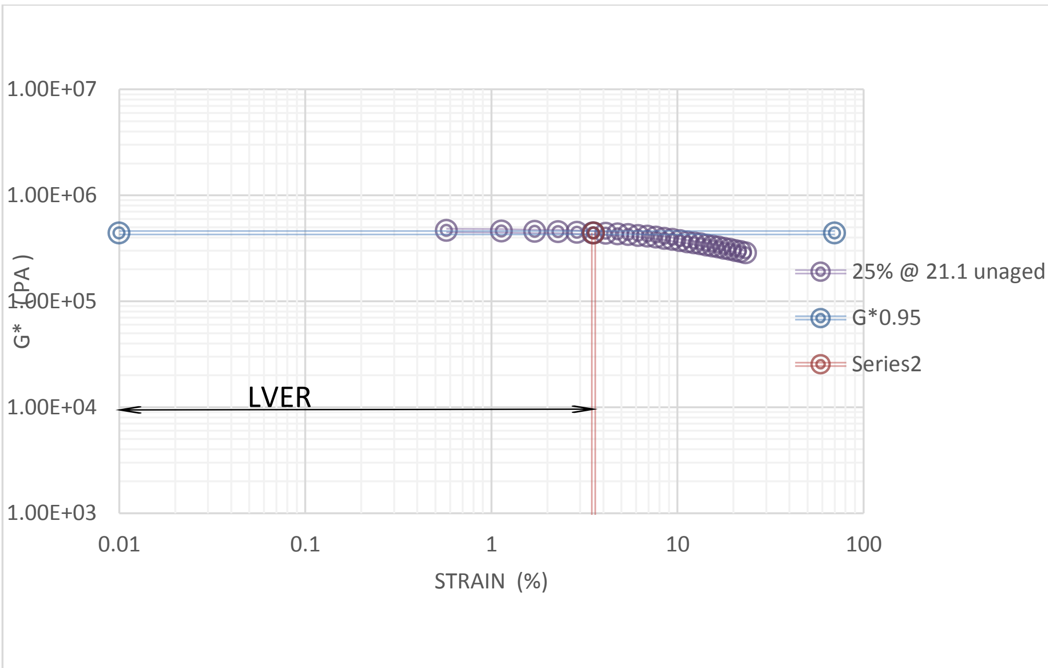


Figure 4.5. Typical LVE Range for 25% Waste Tire (21.1^{o}C)

Table 4.3shows the Visco-elastic range for all types of the binders increased when the corresponding temperature increased. This is because at high temperature the binder becomes more viscous.

Table 4.3.Visco-elastic region for aged and unaged binder mixes

Waste Tire Content	Temperature(C^o)	LVE range strain value (%)	
		Unaged	Aged
0%	10	0.05	0.03
	21.1	1.32	1.07
	37.8	6.53	5.68
	54.4	39.97	35.41
10%	10	0.09	0.09
	21.1	2.90	1.71
	37.8	8.37	6.28
	54.4	44.10	43.85
20%	10	0.29	0.29
	21.1	3.76	3.51
	37.8	9.84	9.36
	54.4	47.40	44.63
25%	10	0.25	0.10
	21.1	3.54	3.14
	37.8	9.01	5.76
	54.4	23.39	19.47
30%	10	0.22	0.04
	21.1	2.23	2.08
	37.8	8.51	4.84
	54.4	15.54	14.88

The addition of different percentage of Waste Tire affected the rheological property of asphalt binder differently. As it can be seen from the Figure 4.6 and the Table 4.3addition of waste tire has effect on the rheological property of asphalt binder. From the table above we can see clearly the proportion of waste tire increased from 10% to 20% the LVER increased with temperature whereas further increased waste tire from 20%-30% the LVER decreased with the same temperature. These show that when the amounts of waste tire increase the stiffness of the binder increases. More over from the high temperature (54.4C^o) amplitude sweep test result the minimum strain value registered at 30%. Therefore it is convenient to use the standard strain 12% and 10% as an input for performance grade determination of the modified binders of this study before and after RTFO Ageing respectively. According to the standard test method AASHTO T 315 for specific binder above 12% and 10% are to be used for PG determination if and only if these values are below the limiting strain value, i.e.; within the linear visco-elastic region of a specific binder.

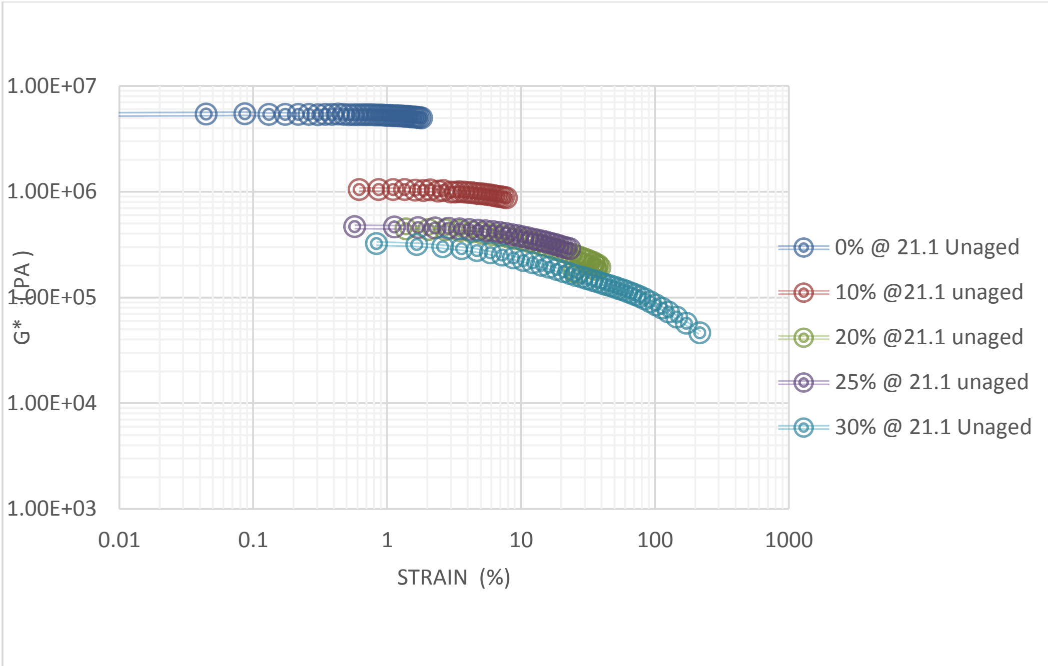


Figure 4.6.The effect of Waste Tire on Asphalt binder on a typical temperature (21.1°C)

4.2.2. Frequency Sweep Test (FST)

Frequency sweep test was set from high to low frequency (25Hz-0.1Hz) in an increasing damaging effect. Frequency sweep test results at 10.0C°, 21.1C°, 37.8C°, and 54.4C° for all samples both aged and un-aged were determined and organized as stated below.

Before the final master curve is developed, shear modulus as a function of reduced frequency is plotted to illustrate how the temperature shift factors were used as shown in figure 4-5 below.

And reduced frequency is calculated as;

Log fr = Log f +At,

Where; fr is reduced frequency, f is frequency and At is temperature shift factor

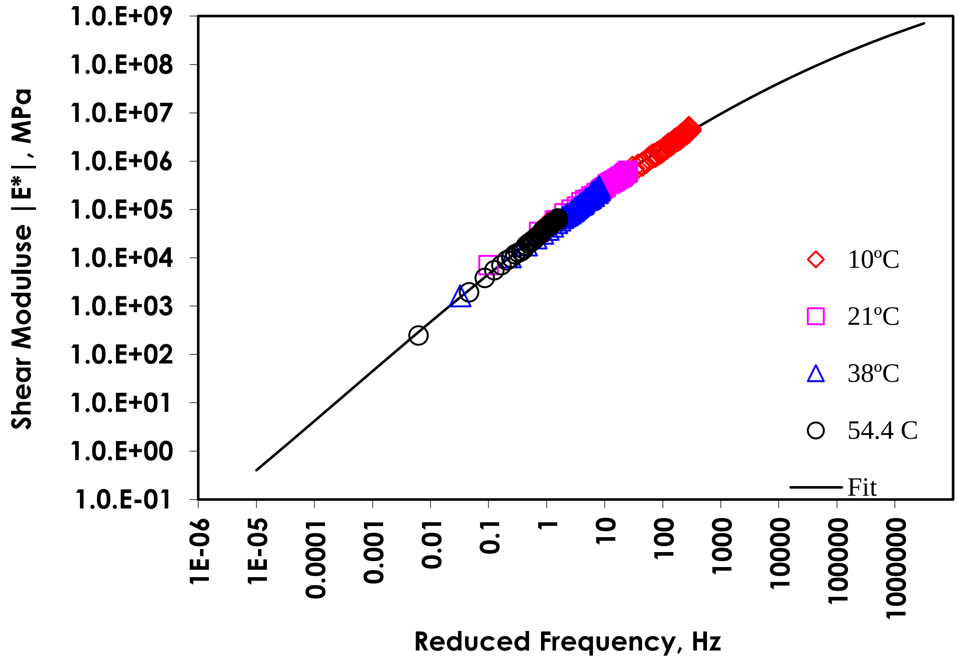


Figure 4.7 Temperature Shift at 21.1 C^{o} Ref. Tem. for 25% Waste Tire after RTFO

4.2.2.1. The Effect of Waste Tire on Frequency Sweep Test

Figures 4.8 presented the DSR frequency sweep test results shear modulus versus Frequency and phase angle versus Frequency for 25% waste tire.

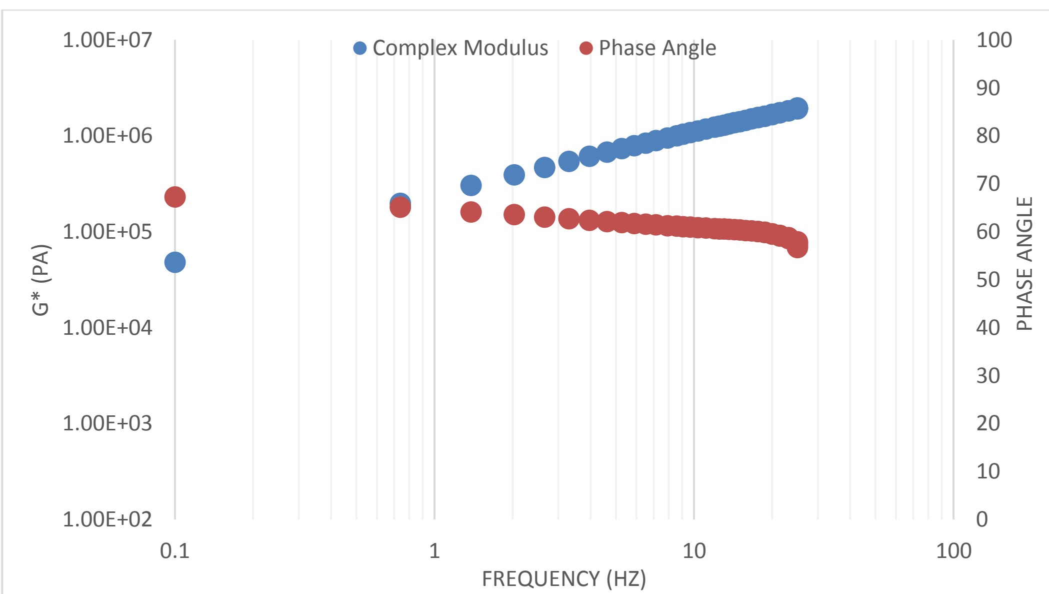


Figure 4.8. Frequency sweep test result for Unaged 25% Waste Tire (21.1C^{o})

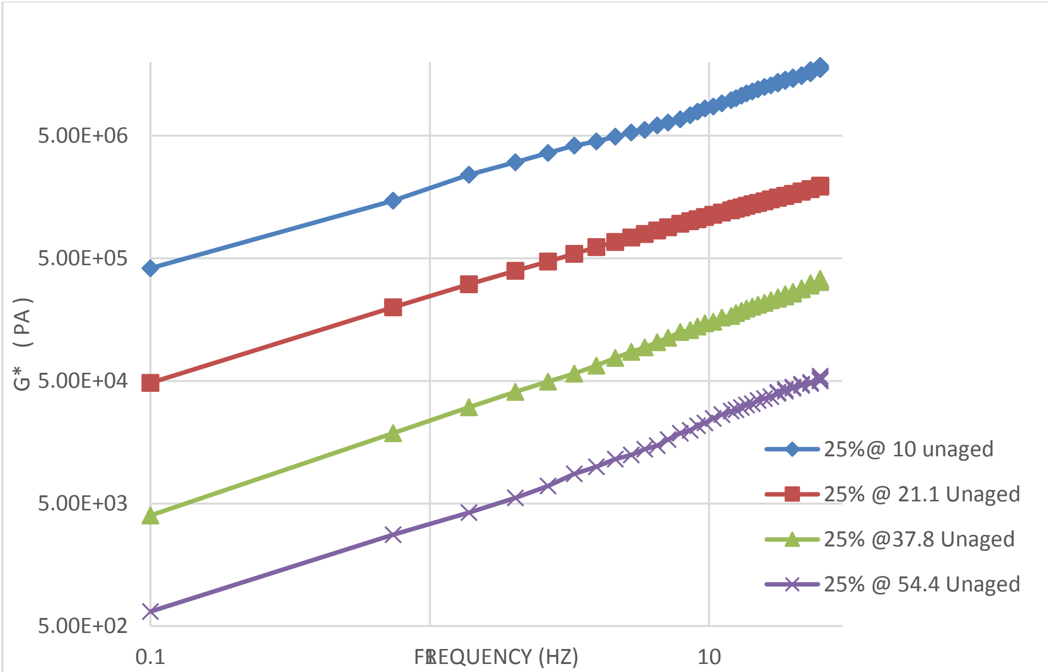


Figure 4.9.Complex modulus verses frequency for Unaged 25% Waste Tire

We can concluded from the Figures 4.9, when the complex modulus values increased with the incremental of frequency, while the complex modulus decreased when the temperature increased and the phase angle values have increased when frequency decreased.

In general, the dynamics shear modulus increased due to the rise of frequency based on the fact that the material is in the plastic region at low frequencies (high values of phase angle). More figures related to FST results were presented in appendix B**.** Frequency sweep tests were performed in order to construct master curves that determined the rheological properties of the binders. Dynamic shear modulus at different test temperatures and frequencies were determined by using the time temperature superposition principle. In constructing the master curves using the time temperature superposition principle, test data collected from the DSR Test at different temperatures and loading times, in terms of dynamic shear modulus & Phase angle, were compared to a reference temperature, which is in our case 21.1 °C. The data at any other temperatures were shifted with respect to time until various curves overlap almost perfectly to form a single master curve. Different scholars use different models for shifting to single reference temperatures. However, a research developed at the University of Maryland showed that the master curve for binders can be represented by a sigmoidal function (M. Abukhettala, 2016).

Table 4.4. Shift factors for complex modulus master curves for aged and unaged binder

Aging Condition	Waste Tire Content (%)	α	β	δ	γ	a10.0	a21.1	a37.8	a54.4
unaged	0	44.659	-1.489	-30.69	0.121	0.132	0.000	-1.135	-2.497
	10	52.123	-2.085	-40.66	0.164	0.203	0.000	-1.280	-1.390
	20	51.708	-1.853	-39.17	0.133	1.165	0.000	-1.351	-2.266
	25	51.017	-1.525	-36.57	0.099	1.363	0.000	-1.197	-2.229
	30	51.722	-1.931	-39.99	0.131	1.255	0.000	-0.970	-2.010
aged	0	51.005	-2.228	-39.86	0.144	1.745	0.000	-1.555	-3.048
	10	42.786	-1.107	-26.42	0.105	0.400	0.000	-1.158	-2.129
	20	48.894	-1.298	-32.63	0.092	0.300	0.000	-1.576	-2.386
	25	52.690	-1.650	-39.59	0.127	1.060	0.000	-0.498	-1.216
	30	51.840	-1.878	-40.12	0.148	0.908	0.000	-0.571	-1.640

The parameter α is defined as minimum stress level that would cause the damage; δ + α are defined as the maximum stress that would cause instantaneous damage; and the β and γ are described as the shape of the sigmoidal function. All of these values vary for each binder type. As for the temperature shift factors, $a_{21.1}$ is zero for all the binder types because all the parameters are shifted to 21.1ºC. Whereas for$a_{10.0}$values are all positive and $a_{37.8}$& $a_{54.4}$the values are negative because the stiffness parameters are shifted to reduced temperature, which is 21.1ºC.

Shear modulus master curves for unaged Binder

From the Figure 4-10 it can be seen that for all binders in almost similar pattern shear stiffness decreases as temperature increases. Unaged Waste Tire modified binders have higher modulus than bitumen binder except 10% at low frequencies and higher temperature whereas at higher frequency and low temperature the bitumen binder has lowest modulus than binder containing waste tire. Therefore it has an advantage there by improving the property of asphalt binder for low frequencies or higher temperature conditions except 10% contain binder.

From above we can generalize that the modifier appreciably improves the complex shear modulus of the bitumen binder at higher temperatures. At high temperature due to slow moving traffic, the rutting is serious problem and as observed, the waste tire improves the pavement performance against this distress by increasing the stiffness of the binder.

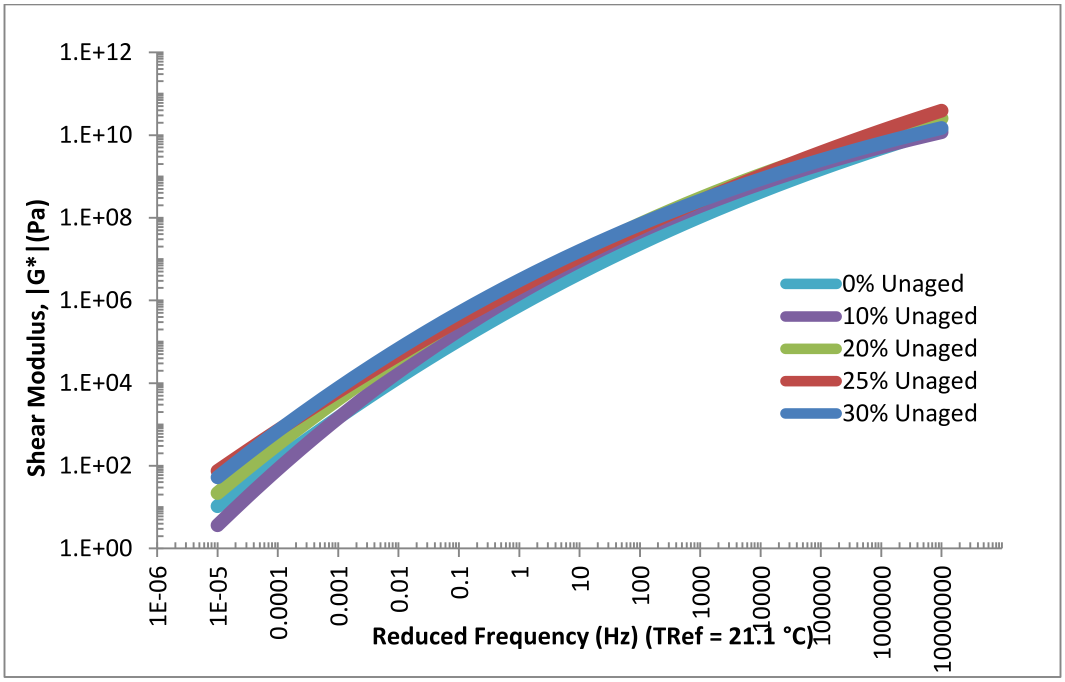


Figure 4.10. Complex Modulus Master Curves for Unaged Binder

Shear Modulus Master Curves for Aged binder

From the Figures 4-11 aged bitumen binder have lowest shear modulus than aged modified binders at low frequency but at higher frequency bitumen binder has almost the same shear modulus with 10% and 20% whereas less than at 25% and 30% waste tire containing binders. Therefore bitumen binder more affected by aging than binders containing waste tire.

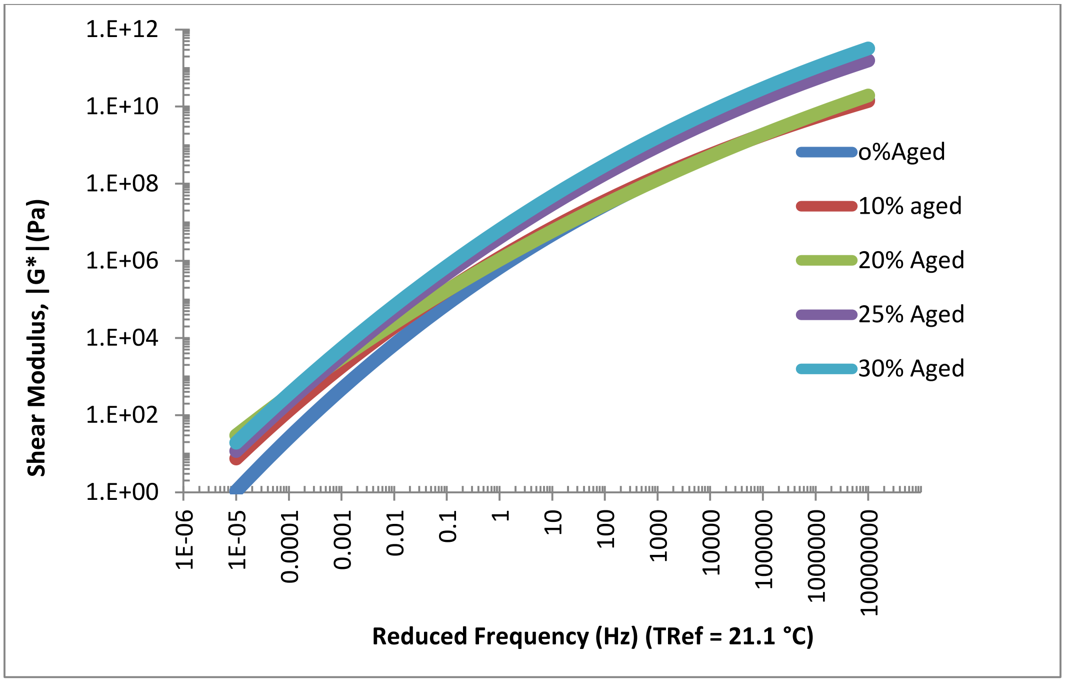


Figure 4.11. Complex Modulus Master Curves for aged Binder

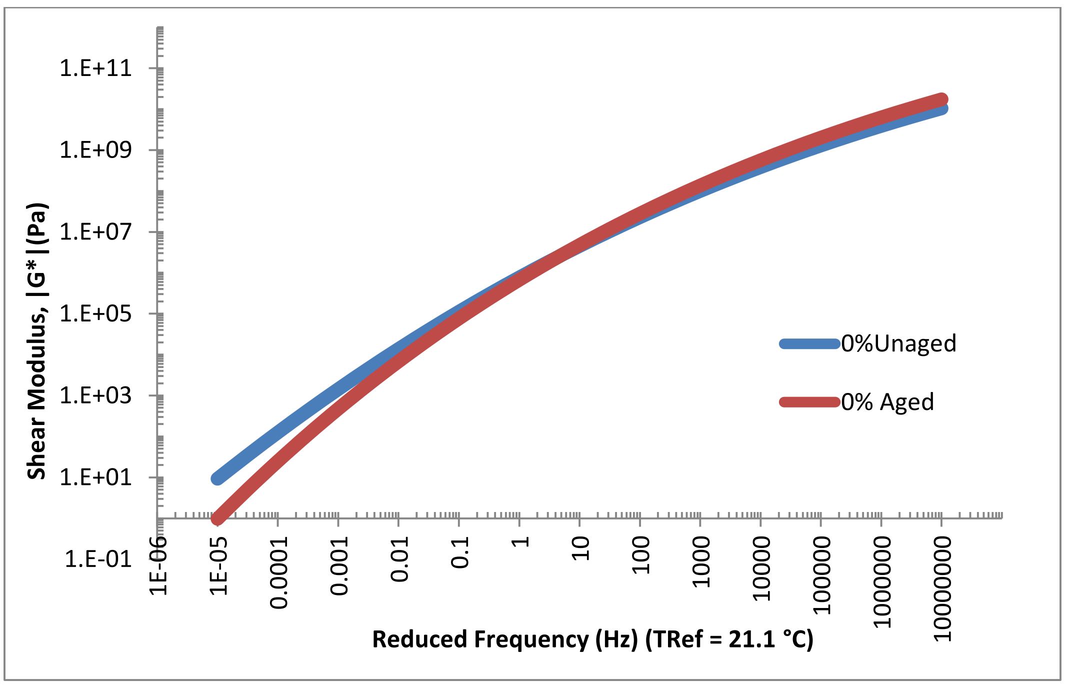


Figure4.12.The effect of aging on Original Binder

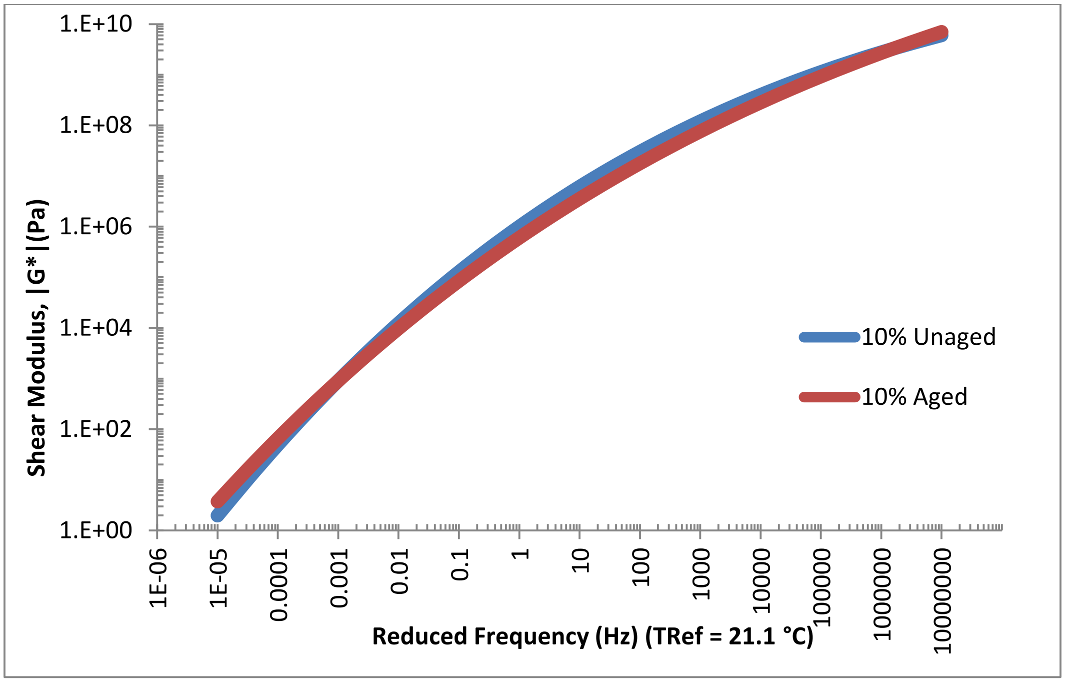


Figure 4.13.The effect of aging on 10% Waste Tire Binder

From Figures 4.12 and 4.13 we can concluded that the asphalt binder containing waste tire is less affected with aging compared to the bitumen asphalt binder which is an additional advantage for the mixed binder i.e. the presence of waste tire in the bitumen reduces the aging effect of a binder.

Frequency sweep data were also used for the construction of phase angle Master curves.

Phase angle Master curves are shown below

Table 4.5. Shift factors for Phase angle master curves for aged and unaged binder

Aging Condition	Waste Tire Content (%)	α	δ	γ	a10.0	a21.1	a37.8	a54.4
unaged	0	3.245	0.387	0.456	1.034	0.00	-1.561	-0.745
	10	5.234	0.792	1.002	1.023	0.00	-1.293	-0.761
	20	4.934	-0.971	1.026	1.192	0.00	-0.745	-0.451
	25	3.451	0.462	0.974	0.872	0.00	-0.543	-0.013
	30	4.171	0.342	0.437	0.021	0.00	-0.359	-0.016
aged	0	7.645	0.962	0.464	0.906	0.00	-1.422	-0.671
	10	6.77	0.879	0.509	0.672	0.00	-1.04	-0.766
	20	3.132	-0.130	1.096	1.013	0.00	-0.115	-0.059
	25	3.142	0.545	1.207	0.848	0.00	-0.552	0.00
	30	3.49	0.415	1.075	0.00	0.00	-0.493	0.00

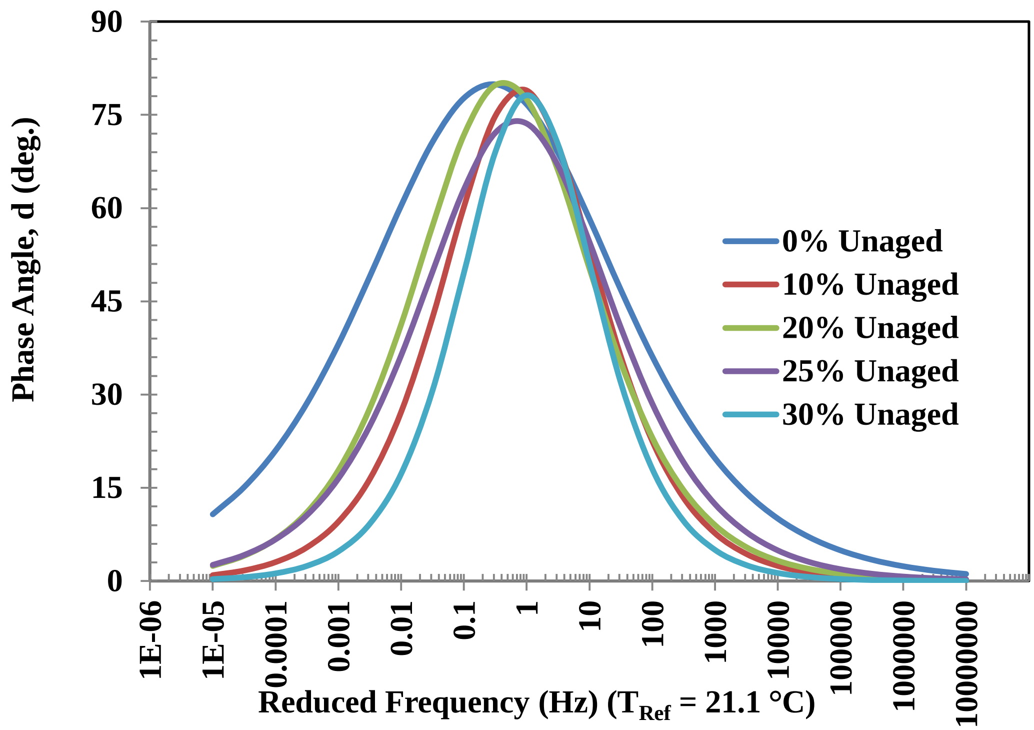


Figure 4.14. Phase angle master curve for unaged binder

Comparing phase angle master curves before and after RTFO ageing it is possible to say that the bitumen binder is more sensitive for aging than bitumen containing taste tire binders. In general, to consider the realistic loading conditions of pavements, frequencies from 0.01Hz to 10Hz need special observation. At these range of frequencies improvement in elastic property of the modified binders is observed due to replacement of bitumen. In other words with in this operation range of frequency as a result of the increase in percent of Waste Tire shear stiffness increases while phase angle decreases.

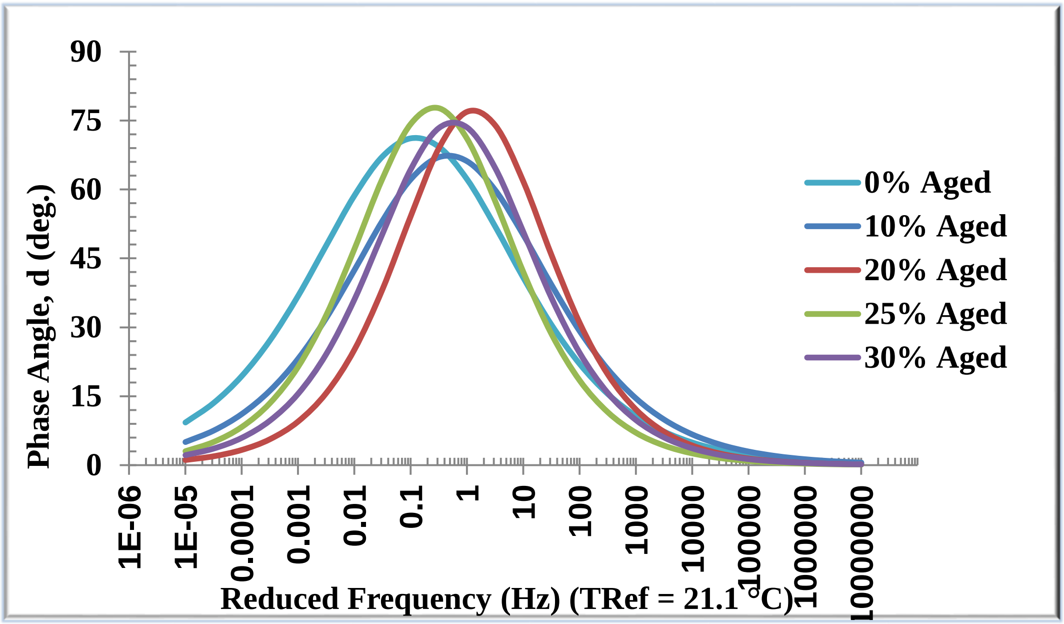


Figure 4.15. Phase angle master curves for aged binder

Figure 4.14 and 4.15 showed that Phase angle master curve demonstrate the decrease in phase angle at high temperature and low frequency whereas the waste tire content increases. It is well known that the decrease in phase angle indicates the increase in elasticity of the binder.

At low temperature and high frequency addition of waste tire in asphalt binder has almost no effect. While at high temperature and low frequency conditions waste tire has high effect on asphalt binder.

Additional FST related results are presented in **Appendix B.**

4.2.3. The effect of Waste Tire on performance grade

From the table 4-6 it is observed that there is a PG grade improvement from PG 64 to PG 70 when the bitumen binder is replaced with 25%Waste Tire. When the content of the modifier is increased to 30% then the PG decrease to 64.The increment in PG clearly shows that modifying bitumen with this Waste Tire material increases the stiffness of the asphalt binder. In general, the addition of different percentage of Waste Tire (10%, 20%, 25% and 30%) changes the grade of the bitumen binder differently.

Here it is understood that the basic rheological parameter, complex shear modulus (G*) is increasing as percent content of Waste Tire increases up to 25% and then decreased. Based on this it is possible to say that the improvement in rutting performance was pronounced due to the addition of Waste Tire modifier. But these days it is proven that the current performance grade stiffness parameter (G*/sin δ) is less in predicting rutting potential. Therefore it is better to further evaluate the modified binder by running Multiple Stress Creep Recovery (MSCR) tests since the parameter from this test termed as non-recoverable creep compliance best relates with rutting than any other parameter from binder test.

Table4.6Performance grade result for unaged neat binder

Temperature (C^o)	Frequency (Hz)	Phase Angle (0)	Complex Modulus (Pa)	Elastic Modulus (Pa)	Viscous Modulus (Pa)	Complex Viscosity (Pas)	Shear Stress (Pa)	Strain ( )
58.02	1.60	85.24	6940	602	6930	698	832	0.118
63.8	1.60	86.97	2850	169	2845	288	345	0.118
70.04	1.60	87.88	1250	54.4	1240	127	197	0.119
75.97	1.60	88.64	591	18.1	591	59.9	80	0.121
Pass Fail :	71.8							
Grade :	70							

Table 4.7Performance grade result for aged neat binder

Temperature (C^o)	Frequency (Hz)	Phase Angle(0)	Complex Modulus (Pa)	Elastic Modulus (Pa)	Viscous Modulus (Pa)	Complex Viscosity (Pas)	Shear Stress (Pa)	Strain ( )
63.98	1.60	85.61	3060	234	3050	305	309	0.101
70.17	1.60	87.06	1300	66.7	1300	130	131	0.101
Pass Fail Tem :	66.4							
Grade :	64							

Table 4.8Performance grade of all percentage Binder

Age condition	Rubber content	0%	10%	20%	25%	30%
Unaged	pass fail temperature (C^0)	71.8	67.4	69	77.8	73.5
	Grade	70	64	64	76	70
Aged	pass fail temperature (C^0)	66.4	66.2	66.7	72.5	67.2
	Grade	64	64	64	70	64

4.2.4. The Effect of Waste Tire on Multiple Stress Creep and Recovery

The relationship between complex shear modulus and J_{nr} is inversely proportional means when the values of complex shear modulus increase J_{nr} value decrease. From Table 4-9 we can conclude that the temperature increased the Jnr value also increased while the complex shear modulus decrease, the stiffness of the material also decreased. From Figures 4-16, 17, 18 &19 and Table 4-10, show that the total strain was influenced by increasing waste tire. Waste tire containing binders have shown less total strain than bitumen binder at 70C^o but at 64C^o and 58C^o the bitumen binder has highest strain than binders contained waste tire. At 10% the highest total strain registered at 0.1Kpawhen the temperature reaches70C^o and at 3.2 Kpa the highest total strain obtained at 0%when the temperature at 70C^o.Therefore this shows that waste tire improved rutting performance at high temperature. At 0.1kpathe smallest total strain value was obtained from 30%waste tire content at 58C^{o,}64C^o and 70C^o. At 3.2Kpathesmallest strain value registered the same as 0.1Kpa noticed above. In general total strain decreases when the waste tire content increases

It can be concluded that the rutting parameter (Jnr) decreases and percentage recovery increases at all temperatures and stresses due to addition of waste tire. This shows that improved rutting performance of the asphalt concrete surface.

Table 4.9. Classified levels of traffic according to J_{nr} values at 3.2Kpa (AASHTO MP19)

Description	Very heavy Traffic at 58C^o when J_{nr}<1	Heavy Traffic at 58C^o when J_{nr}>1	Heavy Traffic at 64C^o when J_{nr}<2	Standard Traffic at 64C^o when J_{nr}>2
Waste Tire content	20%,25 &30%	0%, 10%	30%	0%,10%,20&25%

Other MSCR test results are shown in Appendix E of the research paper.

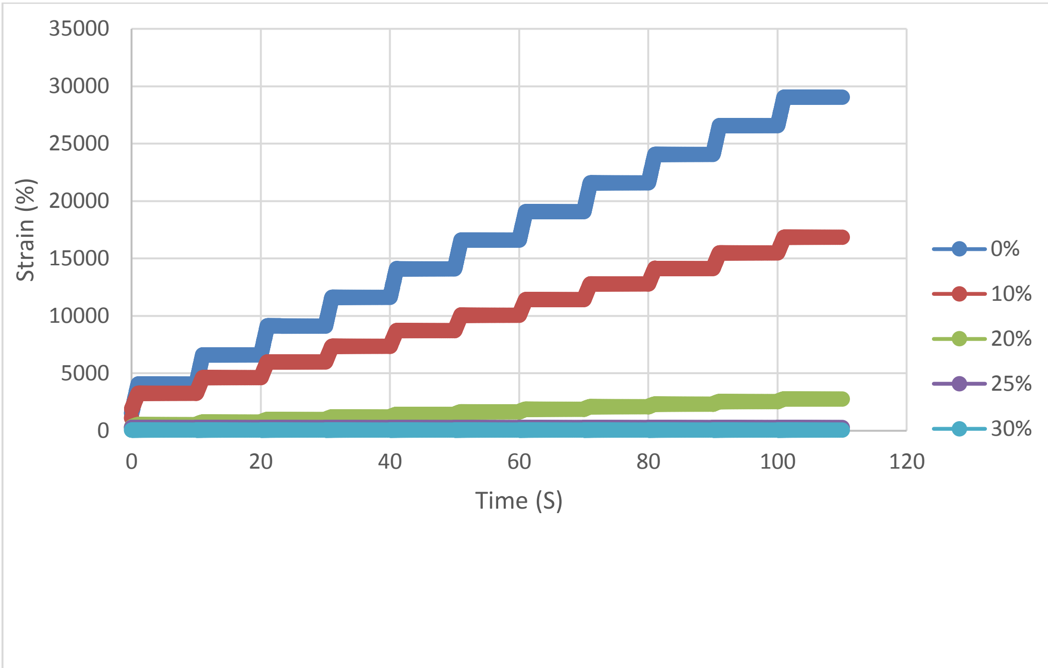


Figure 4.16. Effect of Waste Tire on strain at 3.2 kPa (70°C)

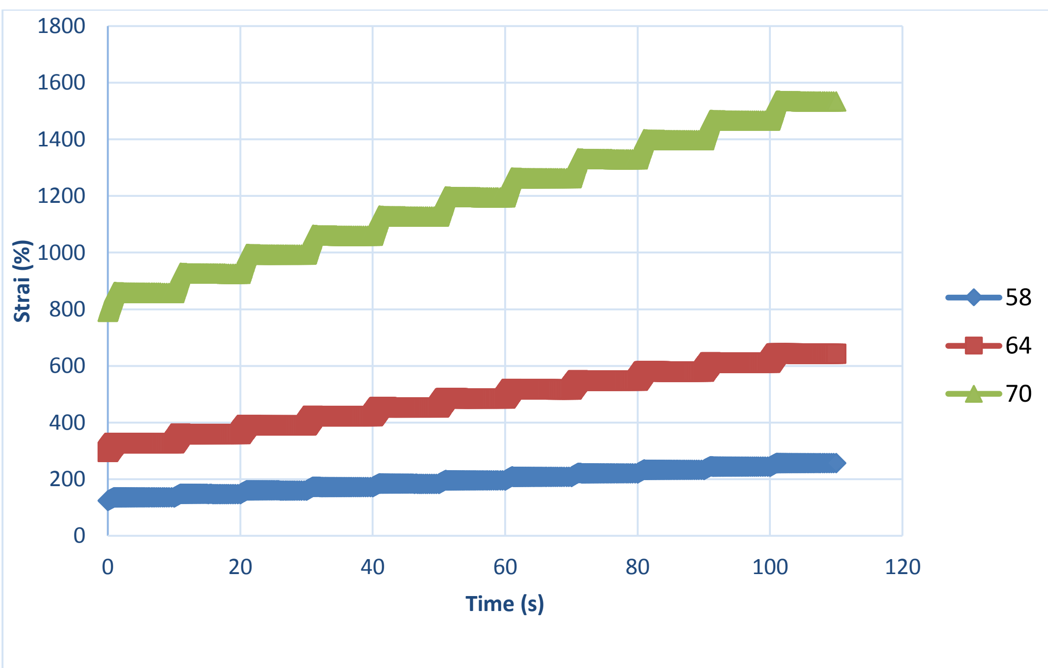


Figure 4.17. The Effect of Waste Tire for 0% at 0.1 Kpa stress

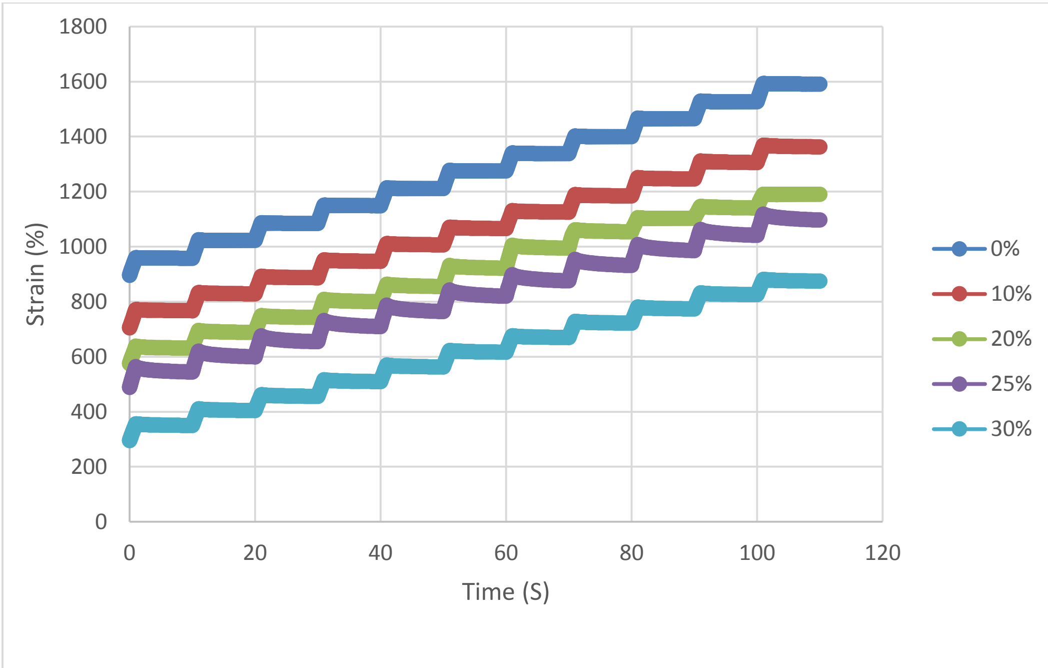


Figure 4.18. Effect of Waste tire on strain at 0.1 kPa (64^{o}C)

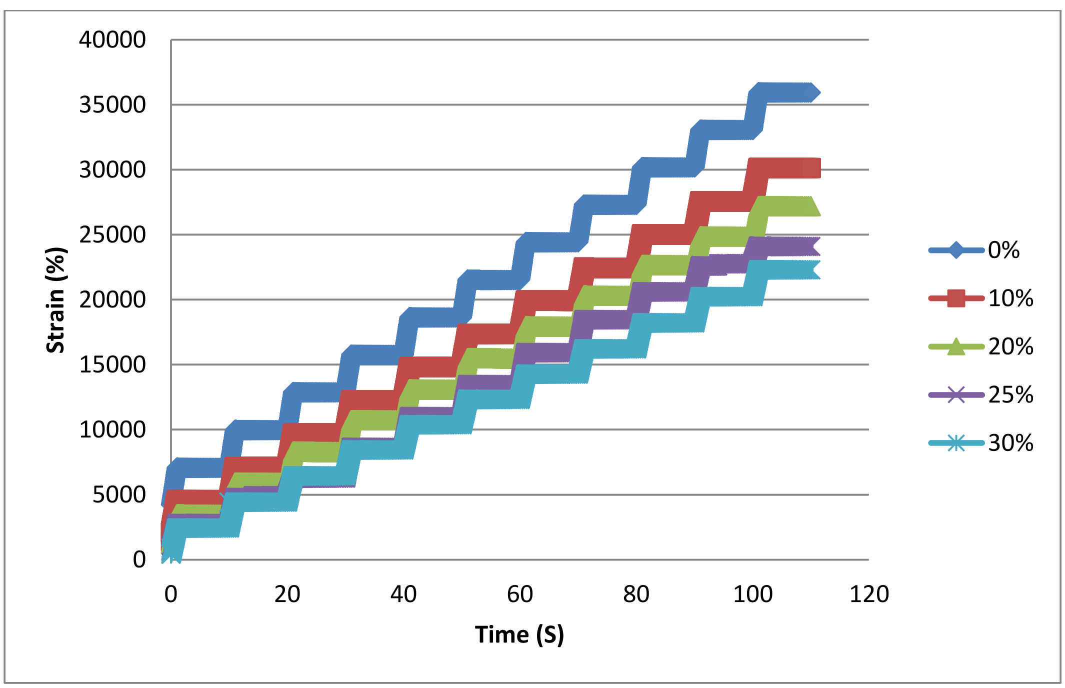


Figure 4.19. Effect of Waste Tire on strain at 3.2kpa (64C^{o})

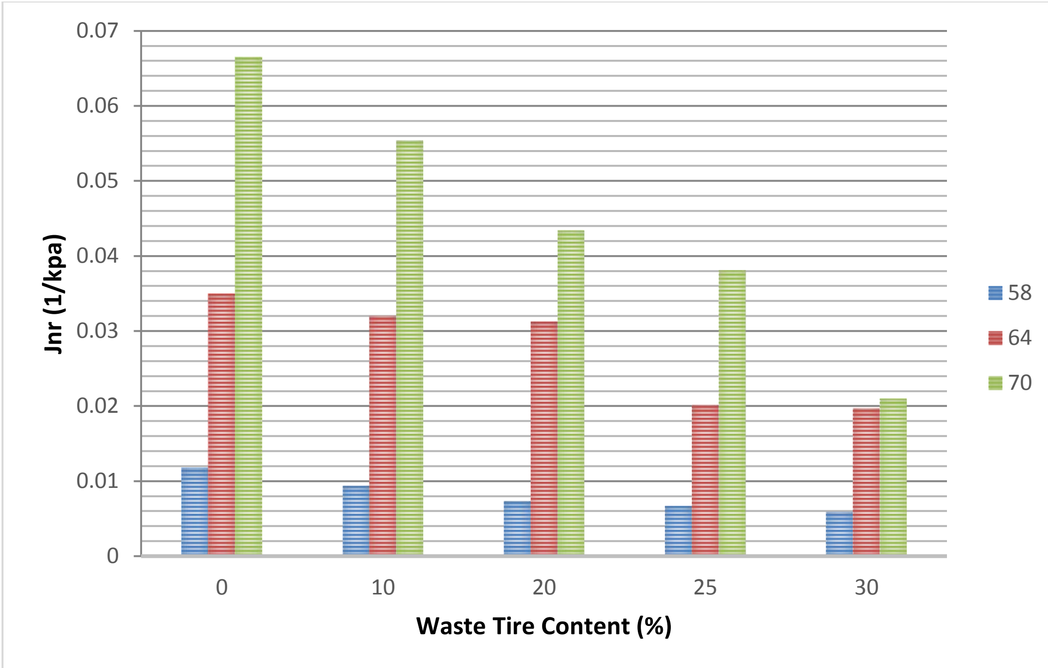


Figure 4.20. Effect of Waste Tire content on Jnr (0.1kpa)

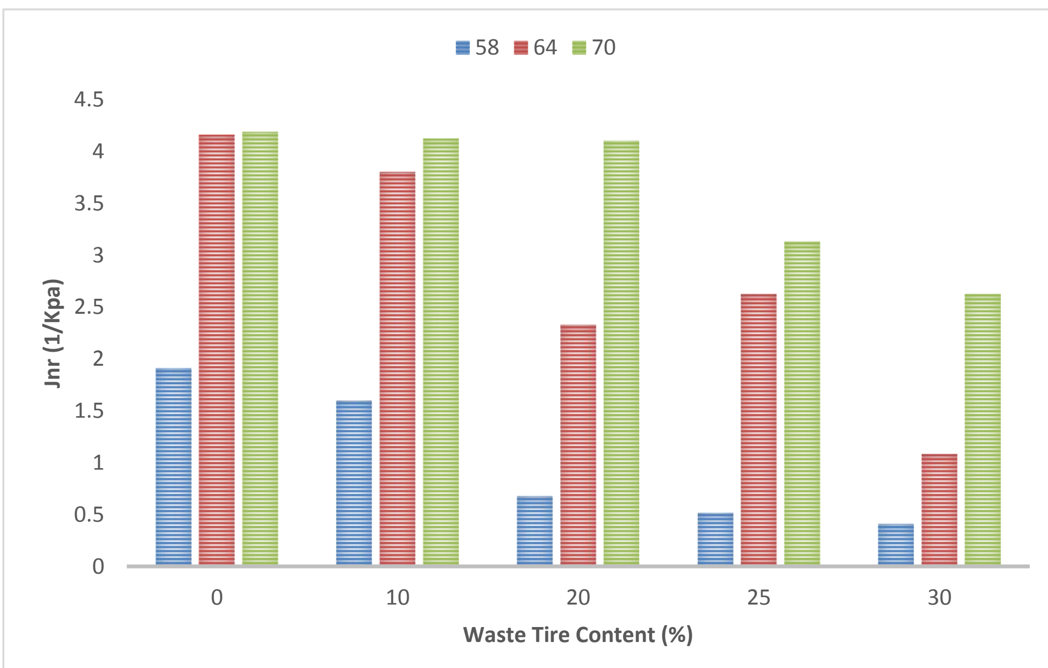


Figure 4.21. Effect of Waste Tire content on Jnr (3.2kpa)

Table 4.10.Summary of MSCR Test

Waste Tire (%)	Temperature (C^{o})	Jnr(1/kpa)		PR (%)	
		(3.2Kpa)	(0.1Kpa)	(3.2Kpa)	(0.1Kpa)
0	58	1.9074	0.0118	2.5857	6.5748
	64	4.1618	0.035	0.8306	3.347
	70	4.1876	0.0665	0.0468	3.8711
10	58	1.5961	0.0094	1.5036	5.4486
	64	3.8028	0.032	0.1768	7.1163
	70	4.1256	0.0554	5.2802	13.1211
20	58	0.6777	0.0074	9.8546	15.85
	64	2.3308	0.0313	5.29	15.8509
	70	4.1035	0.0434	3.1081	51.8021
25	58	0.5174	0.0067	0.7439	14.4808
	64	2.6275	0.0202	0.1211	26.2021
	70	3.13074	0.0381	35.2342	5.4566
30	58	0.4088	0.00591	0.5923	17.0814
	64	1.0838	0.0197	2.3456	9.63 68
	70	2.6275	0.021	67.542	87.119

4.3. The Effect of Waste Tire on HMA Properties

4.3.1. Optimum Binder Content

In order to compare the optimum contents of bitumen binder and bitumen contained waste tire different percentage (20%, 25and 30%) laboratory test performed. The optimum Binder Content was found out by taking the average value of the bitumen content correspond to the value of stability, flow, unite weight and volumetric parameter of the mix. From figures 4-22, 4-23 &4-24 the corresponding optimum bitumen content of the mix was found 4.9%, at 20%,25% and 30% waste tire containing binders the optimum binder contents found 4.95%, 5%, and 4.95% respectively. For more information laboratory test results are presented in **Appendix E** of this paper.

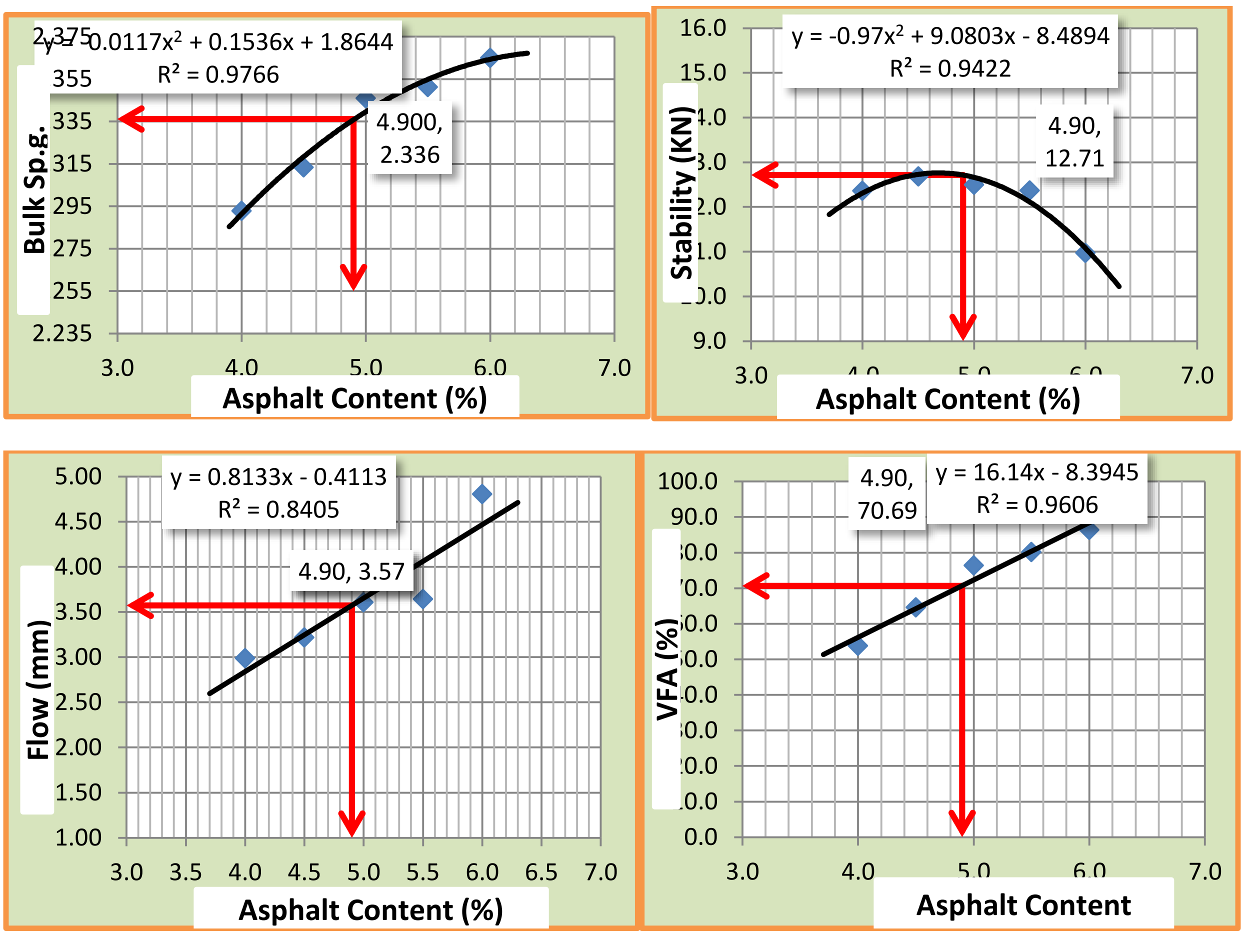


Figure 4.22. Optimum Binder content determination for Bitumen Binder Bitumen

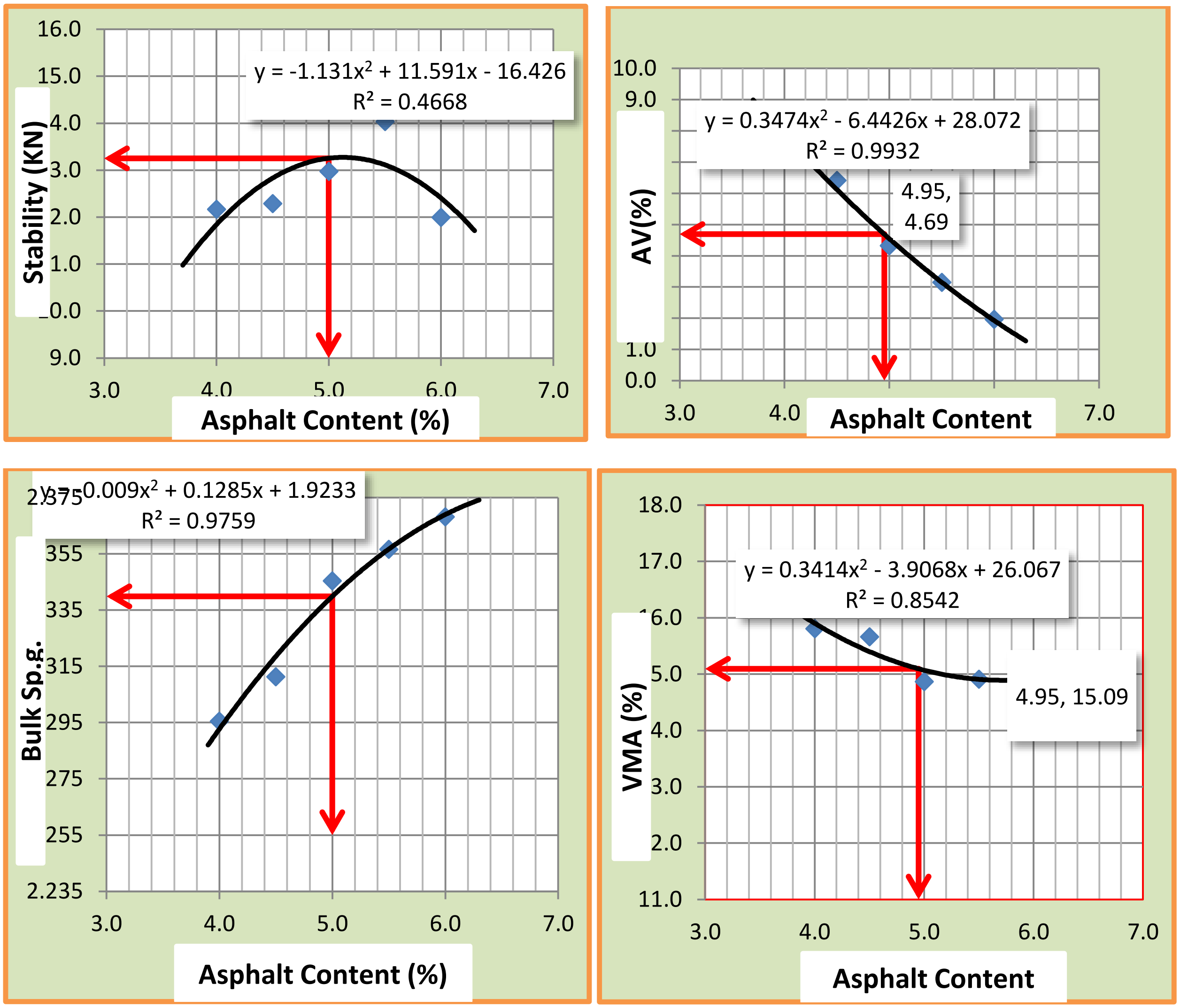


Figure 4.23. Optimum Binder content determination at 20% Waste Tire contained Bitumen

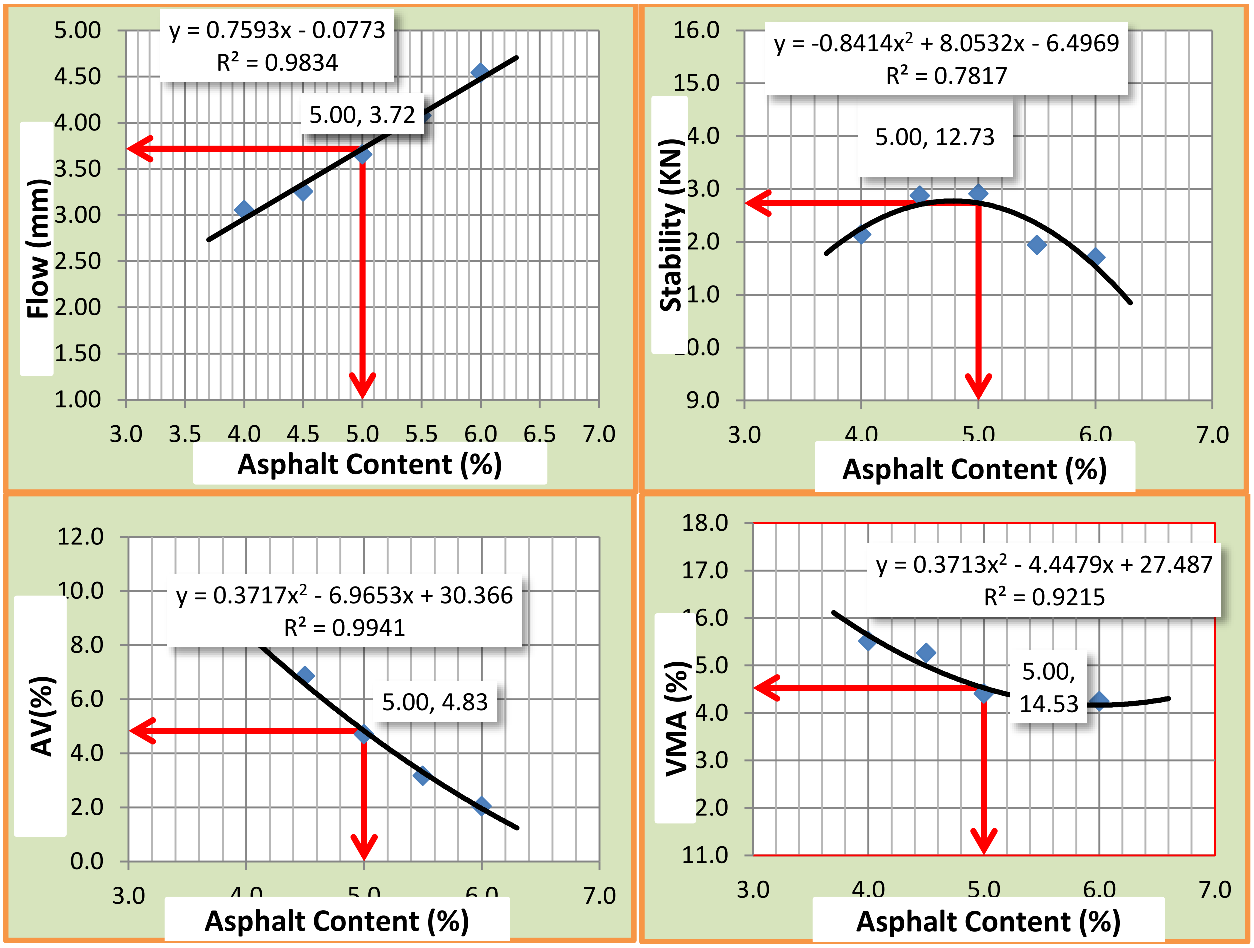
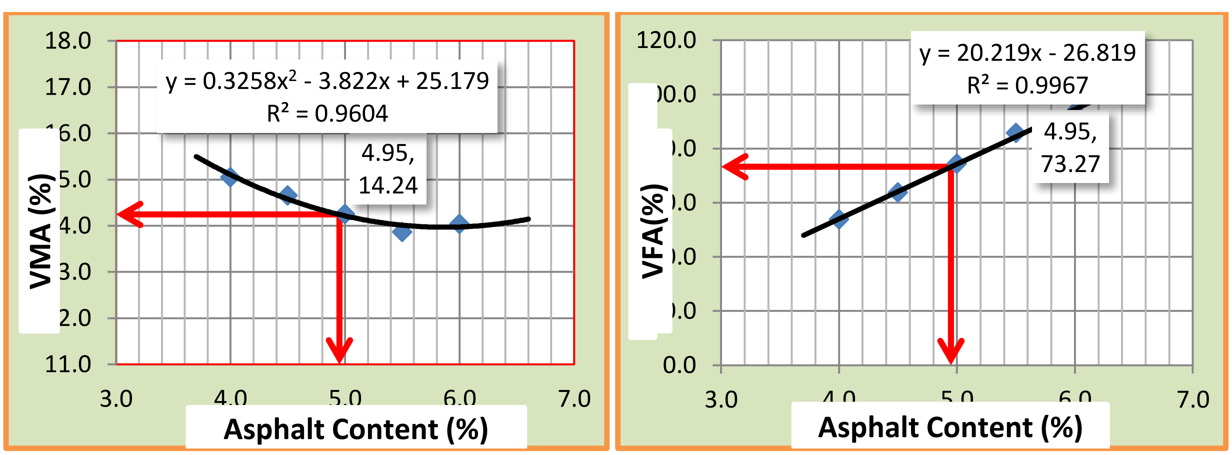


Figure 4.24. Optimum Binder content determination at 25% Waste Tire contained Bitumen



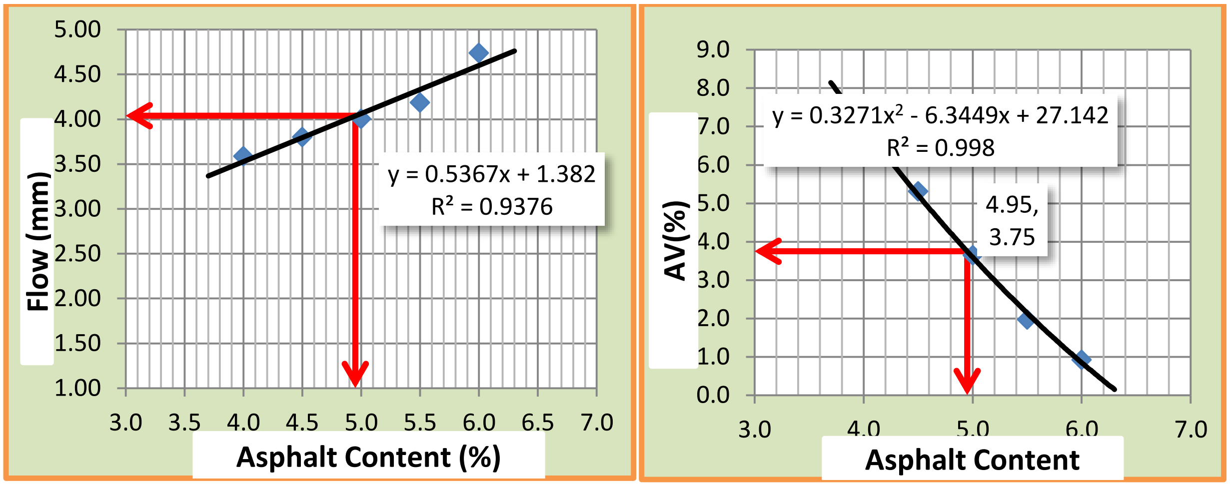


Figure 4.25. Optimum binder content determination at 30% Waste Tire contained Bitumen

4.3.2. The Effect of Waste Tire on Marshall Properties

4.3.2.1. Effect of Waste Tire on Stability

The addition of Waste Tire has influenced the behavior of the asphalt concrete mixtures. The Figure and table4.8 below shows the relationship between Marshal Stability and Waste Tire content. When waste Tire replaces 20% of the bitumen the stability of the mix increased with the need for a slight increase in the binder content (20% of waste tire and 80% bitumen). Further increase in waste tire results in a slight reduction in stability of the mix and binder content. Even though, stability slightly decreased with increase in Waste Tire content, the stability of mixes at Waste Tire content of up to 30% were within the limits of Marshall Criteria for heavy traffic, i.e., above 8 kN.

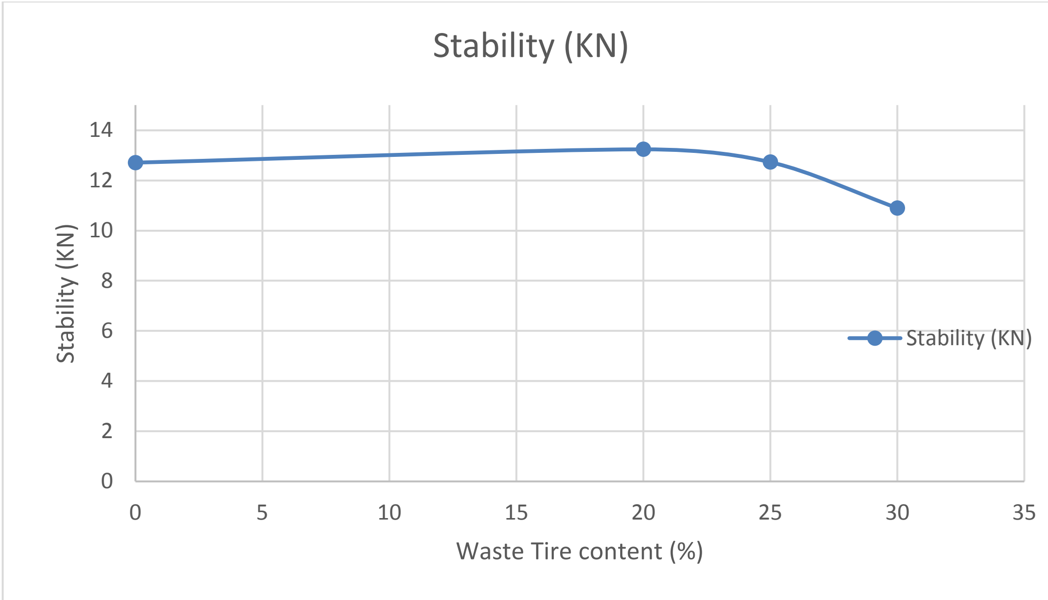


Figure 4.26.The effect of Waste Tire content on Marshal Stability

4.3.2.2. Effect of Waste Tire on Flow Value

Generally, the flow property of the mixture, as shown in Figure and table 4-8 below, the flow value increased by 4% as the Waste Tire content increased by 20%.It can be see also the flow value stays the same when increasing the waste Tire content from 20% to 25%, further increasing waste tire from 25% to 30% the flow value also increased.

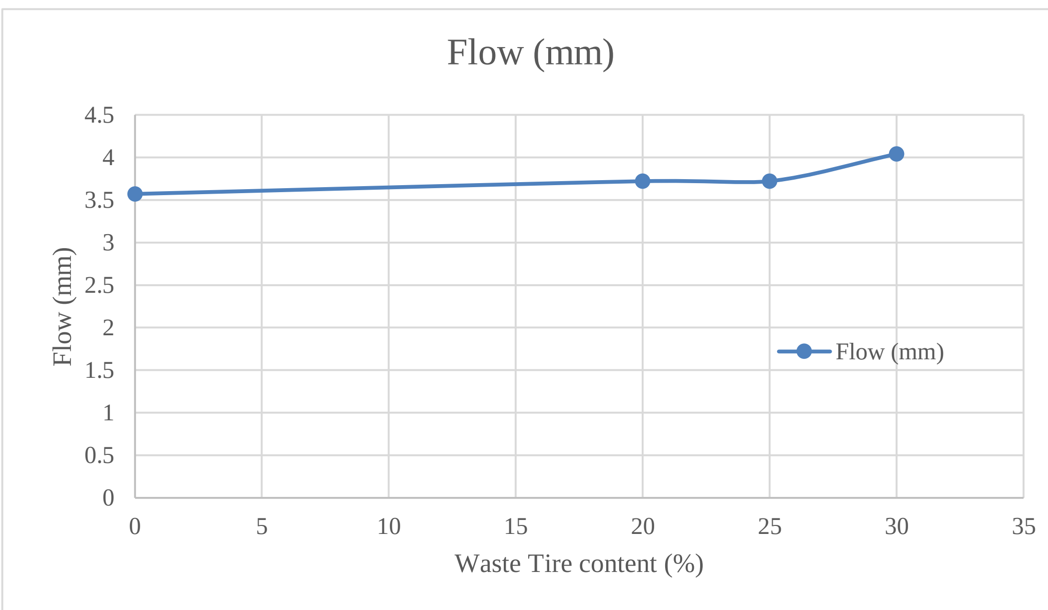


Figure 4.27.The effect of Waste Tire content on Flow

4.3.2.3. Effect of Waste Tire on Bulk Specific Gravity

In general the partial replacement of Waste Tire has no significant effect on the unit weight of the asphalt concrete mixes as shown in the Figure 4.28 and Table 4.8. When waste tire replaces 20% of the bitumen the bulk specific gravity stays the same. Further increase of the waste tire contents from 20% to 30% the bulk specific gravity increased by 0.85%.

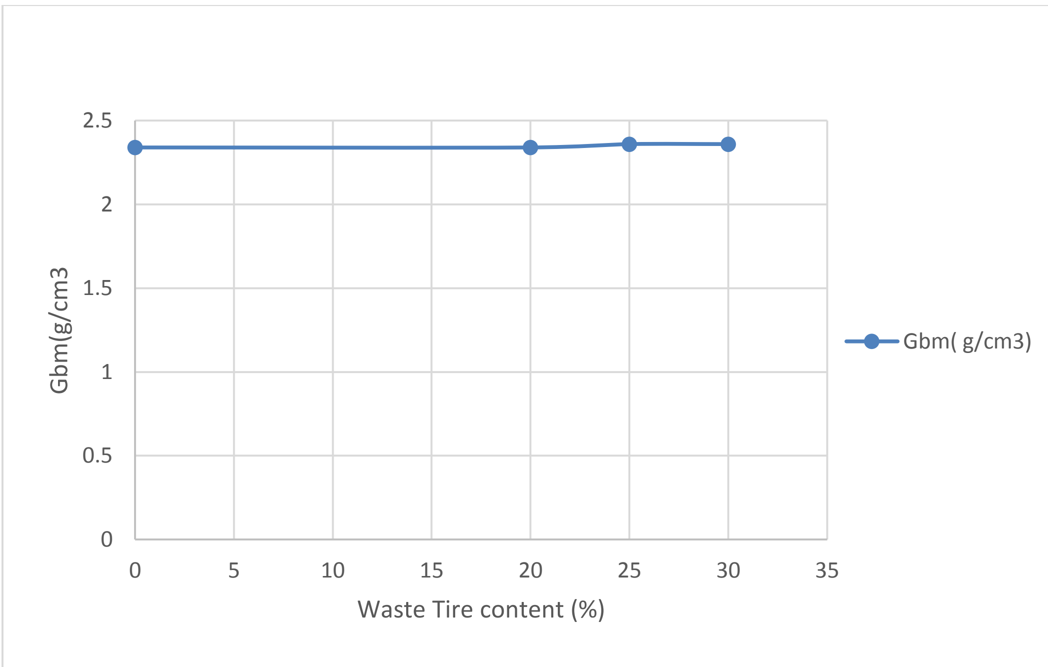


Figure 4.28. The effect of Waste Tire content on Bulk Specific Gravity

4.3.2.4. Effect of Waste Tire on Air Void (AV)

From Table 4.8 and Figure, 4.29 when waste Tire replaces 20% of the bitumen and further increased to 25% the air void increased, but when the Waste tire becomes 30% both the air void and the binder content decreased. It is important to point out that the values obtained at 30% waste tire content for AV are within the specification limits given in the Asphalt Institute Manual Series No. 2 MS-2 that is 3-5%.

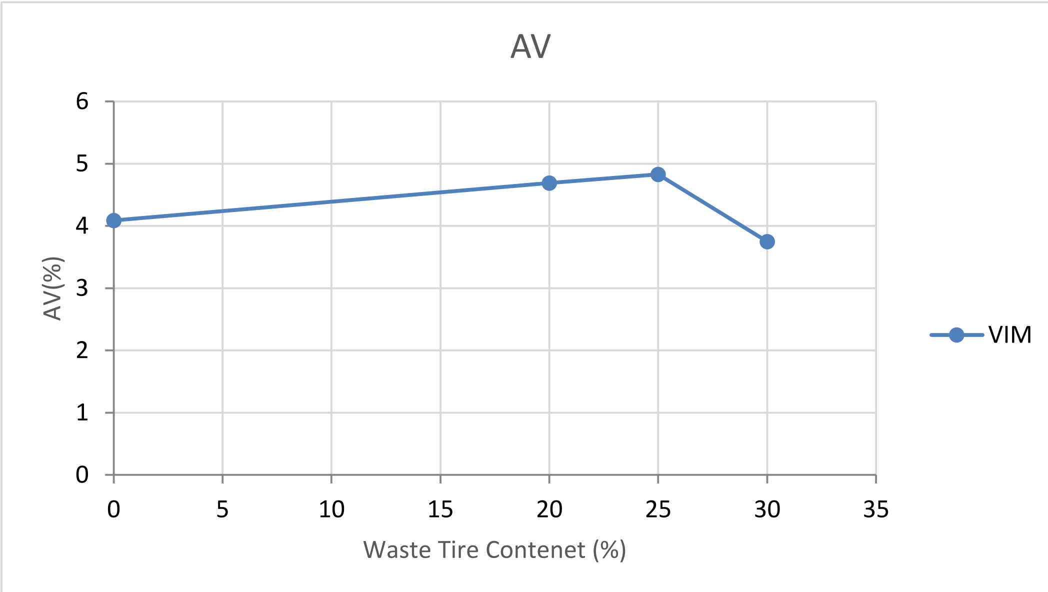


Figure 4.29. The effect of Waste Tire content on AV

4.3.2.5. Effect of Waste Tire on VMA.

According to the result obtained from marshal test the effect of Waste Tire on volume of voids in mineral aggregate is significant. From the Figure 4-30 and Table 4-8 when waste Tire replaces 20% of the bitumen and further increased the VMA of the mix decreased. It is important to notice that the values obtained for VMA are within the specification, i.e. ≥ 13%.

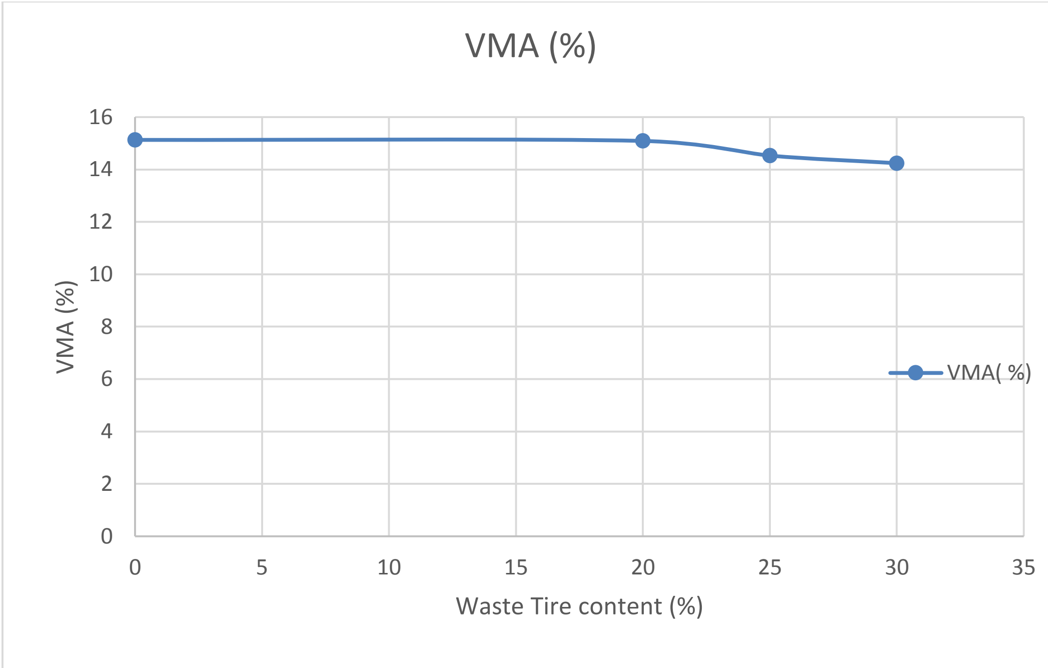


Figure 4.30.The effect of Waste Tire content on VMA

4.3.2.6. Effect of Waste Tire on VFA

As indicated in the Figure 4-31and Table 4-8, the VFA of the mix decreases with increase in Waste Tire content of up to 25% but further increase of the Waste tire to 30% results in the increase of VFA with the decrease in binder content. The reason for such increase can be attributed to the decrease of VMA and increase of AV as Waste Tire content increases from 20% to 25% with the increase in binder content. It is important to point out that the values obtained for VFA are within the specification limits given in the Asphalt Institute Manual Series No. 2 MS-2, i.e., 65 to 75%.

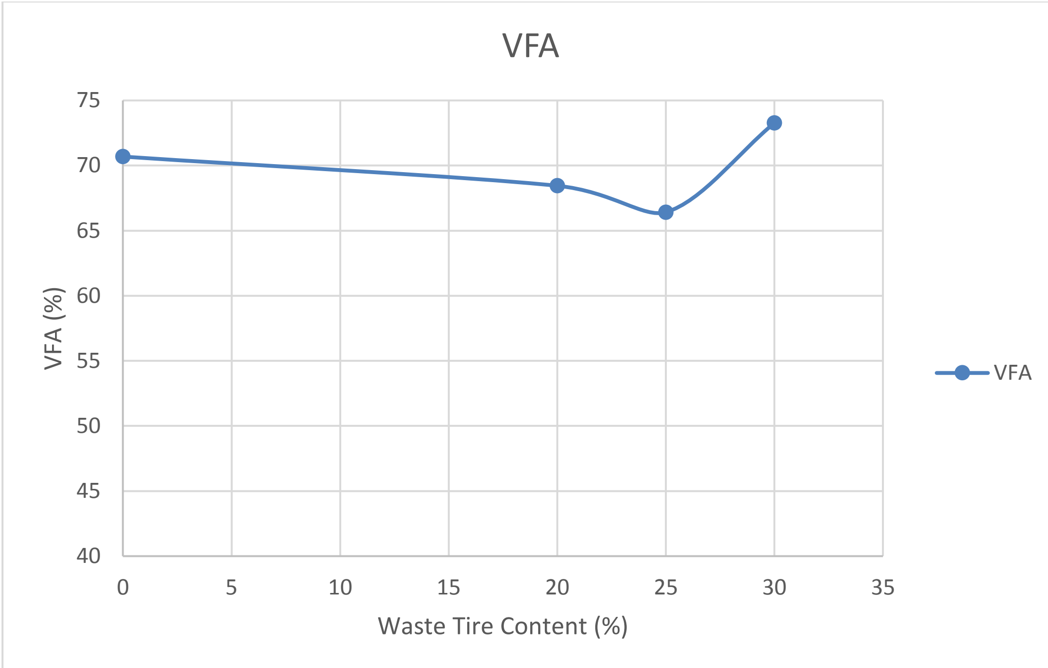


Figure 4.31. The effect of Waste Tire content on VFA

Table 4.11.Summary of Marshall Mix Design Values

Waste Tire content	AC%	AV	VFA	VMA	BSG	Stability	flow
0%	4.90	4.09	70.69	15.13	2.34	12.71	3.57
20%	4.95	4.69	68.45	15.09	2.34	13.24	3.72
25%	5.00	4.83	66.42	14.53	2.36	12.73	3.72
30%	4.95	3.75	73.27	14.24	2.36	10.90	4.04

4.4. Economic Analysis

There are many waste tire recycling plants manufacturer in the world. From that SHEDDER plant has been chosen used for recycling the waste tire by producing 2Tons per hour. Using this machine trying to analyze a simple economic analysis of the Waste Tire to use as a partial replacement of asphalt binder.

SHEDDER plant manufacturer is found Chicago & Miami USA, Montreal Canada, and Shanghai**,** Guangzhou & Chengdu, China. Chose the plant transported from Shanghai port to Djibouti and from Djibouti to Addis Ababa.

Figure 4.32. Partial view of SHEDDER Plant (pictures from manufacturer)

Estimation of Waste Tire disposal

It is difficult to know the exact number of waste tire disposed per year but trying to estimate roughly waste tires get ride per year in the country based on the number of cars and the frequencies of tire changing. The number of cars in the country is 831,265 according to Federal Transport Authority (March 2018), 62 percent of them are found in Addis Ababa and the other 38 percent are found outside Addis Ababa.

In order to estimate the waste tire disposal by dividing in Addis Ababa and outside Addis Ababa because majority of the car riding in the capital, Addis Ababa. From the survey made in Addis Ababa average frequencies of tire changing is once per two years whereas outside the capital once a year.

Accordingly, the final result compiled in the table below and for additional information refer Appendix F, Table F-2.

Table 4.12. Estimated Available Waste Tire in the country

Description	In Addis Ababa	Out of Addis Ababa
No. of cars in (%)	62	38
No. of cars	525,384	315,881
Average No. of Tire per car	4	8
Frequency of Tire change per year	0.5	1
No. Of Tires Wasted per year	1,050,768	2,527,048
Average weigh of Wasted Tire (kg)	9	15
Total Weighs in(kg)	9,456,912	37,905,720
Grand total (kg)	47,362,632	

Machine/Plant related costs.

The total plant price including packaging is given and according to the manufacturer, six containers can pack the plant. Detail information about price and packaging of the plant refer **Appendix** F

Exchange rate taken roughly $1=28Birr

Table 4.13. Total cost of the factory including running Cost

No.	Description	Unit Price (in Birr)
Factory Establishment Cost		
1	Main plant cost in the factory (Manufacturer price)	24, 040,800.00
2	Insurance (from Temesgen Transistor PLC, Addis Ababa)	480,816.00
3	Shipment (From Temesgen Transistor PLC, Addis Ababa)	762,800.00
4	Inland transport (From Temesgen Transistor PLC, Addis Ababa)	482,000.00
5	Warehouse construction for the plant including office facility and store	25,000,000.00
6	Installation and setup of Equipment cost (Manufacturer price)	980,000.00Birr
7	Operators training cost (Manufacturer price)	870,000.00
Total Initial Cost		**52,616,416.00**
Running cost		
1	Employee Cost with 10 employees (manufacturer Requirement) per month	150, 000.00
2	Guards and janitors	14,500.00
3	Maintenance and Operation Cost for System per Month	998,400.00
4	Electric power consumption and water supply	110, 000.00
5	Waste Tire collection up to the plant for 520Tons of Wasted Tire per Month	3,704,134.20
6	Other expenses	150,000.00
Total Running Cost Per Month		5,127,034.20

If the machine works 8 hours a day and 6 days a week it will produce 4,992Tons of waste tire per year. From the whole of the waste Tire 70 percent of it can be used as a binder replacement, that means 0.7 X4, 992 = 3,494.4Tons (3,494,400Kg) can be produced per year.

In order to check the economical visibility of the plant three parameters are selected. This are-

i) Net Present Value (NPV)

Net present value (NPV) is the difference between the present value of cash inflows and the present value of cash outflows over a period of time. NPV is used in capital budgeting to analyze the profitability of a projected investment or project.

√ Net present value (NPV) considers the time value of money for the whole life of projects (lifecycle costs).

√ NPV is the difference between the discounted value of benefits and the discounted value of costs and at the opportunity cost of capital.

$$NPV = \left[\sum_{i=1}^{n} \frac{b_i}{(1+r)^i} - \sum_{i=1}^{n} \frac{c_i}{(1+r)^i} \right]$$

Where:

NPV	=	net present value,
b	=	benefits,
c	=	costs,
r	=	opportunity cost of capital,
i	=	initial year of analysis, and
n	=	last year of implementation period.

According to Total Ethiopia monthly price announcement for the month of April 1Kg bitumen worth 22Birr. Assumed for the economical visibility test 1Kg powdered waste tire worth 22Birr.

Sales per year 3,494,400X22=76,876,800Birr

Expense per year 5,127,034.20X12 =61,524,410.40

Considered annual inflation rate 14% and, salary and other miscellaneous expenses increment of 18%

Table 4.14. Calculation of Net Present Value at Discount Rate of 7 Percent

Year	Cash flow (in Birr)	Net Present Value factor @ 7%	Present value cash flow (in Birr)	Cumulative Net Present Value cash flow (in Birr)
Base Year				-52,616,416.00
1	15,352,389.80	0.935	14,354,484.50	-38,261,931.5
2	15,040,747.70	0.873	13,130,572.70	-25,131,358.8
3	14,242,500.20	0.816	11,621,880.20	-13,509,478.6
4	12,809,747.90	0.763	9,773,837.65	-3,735,640.95
5	10,559,693.40	0.713	7,529,061.39	3,793,420.44
Total				**3,793,420.44**

This project has positive NPV and it is viable

(ii) Discounted Payback Method

The Payback Period helps to determine the length of time required to recover the initial cash outlay in the project. Simply, it is the method used to calculate the time required to earn back the cost incurred in the investments through the successive cash inflows.

- The Discounted Payback Method considers time value of money correcting one of the shortcomings of the Undiscounted Payback Method.
- If the project cumulative benefit greater than or equal to the base year cash flow with in the project life we call it the project is payback its initial investment that specific year.
- The cash flows are discounted to reflect the time value of money.

Table 4.15. Calculation of Discounted Cash Flows in Birr

Year	**Cash Flows in the Project**	**Benefits**	**Cumulative Benefit**
Base year	-52,616,416.00	-	-
1	15,352,389.80	14,354,484.50	14,354,484.50
2	15,040,747.70	13,130,572.70	27,485,057.20
3	14,242,500.20	11,621,880.20	39,106,937.40
4	12,809,747.90	9,773,837.65	48,880,775.05
5	10,559,693.40	7,529,061.39	**56,409,836.44**

- It can be seen in the table above the Project pays back its initial investment in the last year of the project life.

iii) First Year Discounted Benefits (FYDB)

The first year rate of return (FYRR) is a term that is often used to describe the amount of return that is generated during the first year of a specific business initiative, project, or contract. The term is often used to refer to the return after all expenses have been settled that occurs during the first year of the project. In some cases, the first year rate of return is utilized as a means of evaluating the effectiveness of the effort and determining if it will be allowed to continue for another year.

(i) FYDB as a percentage of total discounted benefits (TDB):

$$\text{If } \frac{FYDB}{TDB} X \ 100 > \text{opportunity cost}$$

The project is generating benefits early on, which is beneficial for reinvestment.

$$\text{X} = \frac{14{,}354{,}484.50}{56{,}409{,}836.44} \text{x } 100 = 25.45\% > 7\% \text{ (Opportunity cost)}$$

Therefore, the project is generated benefits early.

From the above three economic parameters we can conclude that the project is viable if it is implemented.

Depreciation of the fixed asset taken 20% per year according to Ethiopian custom and revenue Authority

First year depreciation value

51,746,416 Birr x0.2 = 10,349,283.20 Birr

Total expense per year including depreciation value:

61,524,410.40+870,000+10,349,283.20 = 72,743,693.6 Birr

In order to produce 3,494ton or 3,494,400Kg it will take 72,743,693.6 Birr per year is required. In order to produce 1kg waste Tire it will require 20.82Birr. If we buy and install this plant here, it will reduce the price by 5.365 of the imported bitumen.

Chapter Five: Conclusion and Recommendation

The main goal of this research is to partially replace asphalt binder with waste tire which is a locally available material in order to have more economical pavement structure and better performance. It has also been found that the addition of waste tire on asphalt binder has influence on overall property of asphalt binder.

5.1. Conclusion

This research tried to study the conventional and rheological properties of binder mixes and HMA made from this binder mixes. Based on the results obtained from this study, the following conclusions are drawn:

- The LVER of the binder increased as the waste tire content increased from 0% to 20% and then decrease when the wastes tire content increase to 30%.
- At high temperature and low loading condition the stiffness of the binder increased as the percentage of Waste Tire increased which shows addition of Waste Tire improves asphalt binder properties at high temperatures.
- Bitumen asphalt binder is more affected by aging compared to asphalt binder containing waste tire. Meaning addition of waste tire to bitumen decreases the aging effect of HMA mixtures.
- replacing bitumen by waste tire has affected rheological properties of the asphalt binder. When Waste Tire increased the binder become stiffer at high temperatures, which results in a durable binder.
- Test result obtained from FST master curve shows an improving behavior for asphalt binder up on increment of waste tire. Replacing bitumen binder by waste tire on asphalt binder increases the stiffening property of asphalt binder at high temperatures (low frequencies).
- The strain value and the rutting parameter Jnr decreased as the waste tire content increased which implies partial replacement of waste tire in asphalt binder reduces rutting of pavements.

- The test result obtained from MSCR shows the smallest total strain value was obtained for waste tire content at 30%, followed by 25%, 20% and 10%. Therefore, addition of waste tire improves the rutting resistance of asphalt pavements.
- The penetration and ductility values decreased while the softening point and flash point increased as the waste tire content increased due to the stiffness properties of the waste tire.
- The HMA containing waste tire of up to 25% shows almost the same Marshall Stability and volumetric properties with only slight difference in Binder content with HMA containing bitumen binder. But further increment of waste tire up to 30% of waste tire content shows a change in all the Marshall stability and the volumetric properties compared to the conventional HMA but still within the requirements of the specification.
- when the replacement of asphalt binder by waste tire increases from 20% to 25% it results in the optimum binder content to increase from 4.95 to 5% but further increase to 30% shows a decrease in optimum binder content to 4.95.The stability, flow, unit weight and the AV% increased when waste tire increases from 20% to 25% but decreased when waste tire further increased to 30%. While the VMA value decreased in all percentage values of the waste tire whereas, VFA percentage increased at 30% but decreased at 20% and 25% of the waste tire content. The change in value of these criteria's of HMA are within the Marshall criteria for heavy traffic up to 30% of waste tire content.
- Because of time and economical limitations detailed mixes containing waste tire content above 30% were not conducted in order to determine the optimum waste tire content. The research was done on waste tire content which is applicable only for optimum binder content of 4.95% to5%.
- It can be concluded that it is possible to partially replace asphalt binder by waste tire up to 20% for wearing coarse at hot area.
- According to the simple economic analysis waste tire has less cost than the bitumen we imported. Therefore using waste tire as a partial replacement of asphalt binder is cost effective.

5.2. Recommendation

Based on the study results the following recommendations are made.

- The study showed that it is possible to replace the bitumen binder by waste tire with improved the stiffness of the binder, therefore it is recommendable to use this modified binder in Ethiopia at high temperature.
- The hot area in Ethiopia like Gambella, Semara, Dallo, etc. suitable to use waste tire replaced binder to increase the rutting performance of the pavement. Therefore it would be advisable try to produce and evaluate waste tire replaced bitumen binder using 60/70 penetration grade bitumen as the base material.
- It would be better if Ethiopian Roads Authority support and encourage waste tire replaced pavement technology considering its advantage to minimize pavement distress due to rutting in Ethiopia.
- It is advisable Ethiopian Roads Authority and other stake holders in the area of road construction, it is better to use the latest binder specification system using performance grading and Multiple Stress Creep Recovery test (AASHTO M 332) which is the new method that best relates with rutting performance. Moreover it is because binder characterization has to be considering specific local condition of loading, temperature and others.
- By establishing waste tire crusher plant in Ethiopia it is possible to reduce the bitumen import and will create local job opportunity.

5.3 Future Study

There is always the opportunity for future research in the area of asphalt binders and mix characterization. For this reason, future research work may include:

1. Further studies are needed to characterize binders composed of Waste Tire and asphalt binder using different grade bitumen.
2. Further studies are needed to characterize the chemistry of binders composed of Waste Tire and asphalt binder.
3. Moisture susceptibility shall be investigated with the different Waste Tire contents.
4. Life cycle cost analysis must be conducted for roads constructed using Waste Tire in comparison to those constructed using conventional asphalt binder.

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Appendix A - Amplitude Sweep Test Results

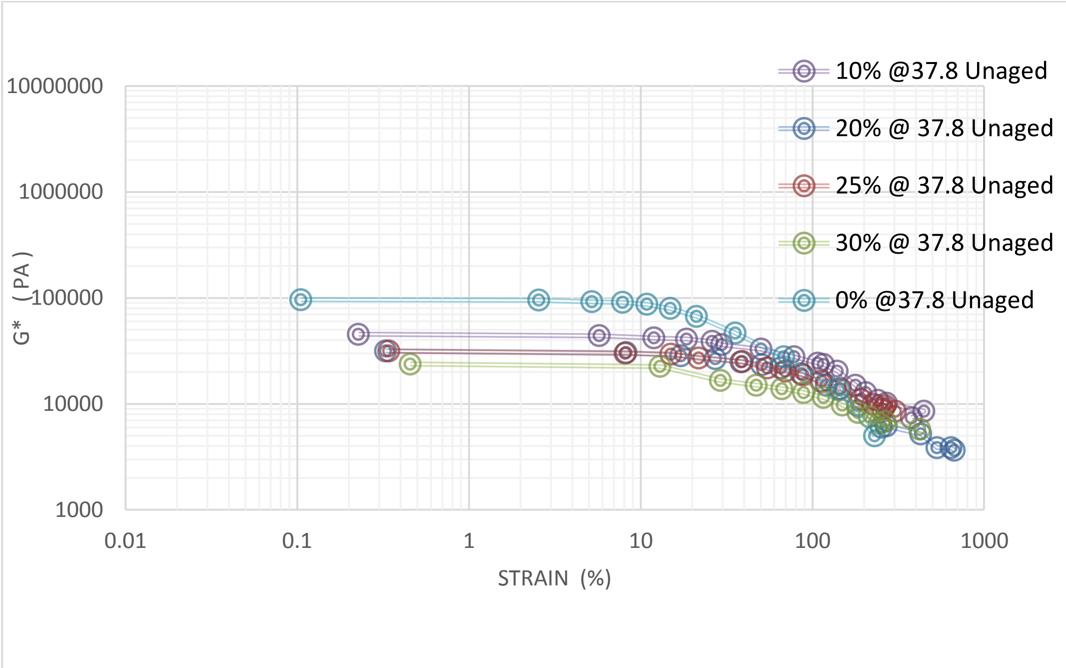


Figure A.1. The effect of Waste Tire on asphalt unaged binder at 37.8°C

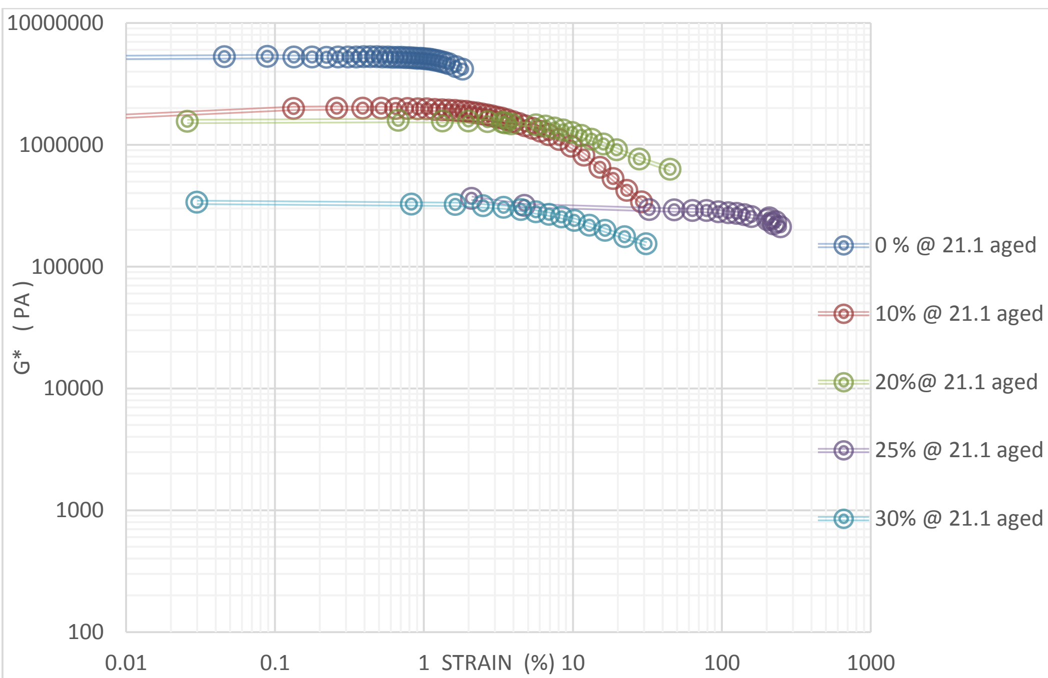


Figure A.2. The effect of Waste Tire on asphalt aged binder at 21.1°C

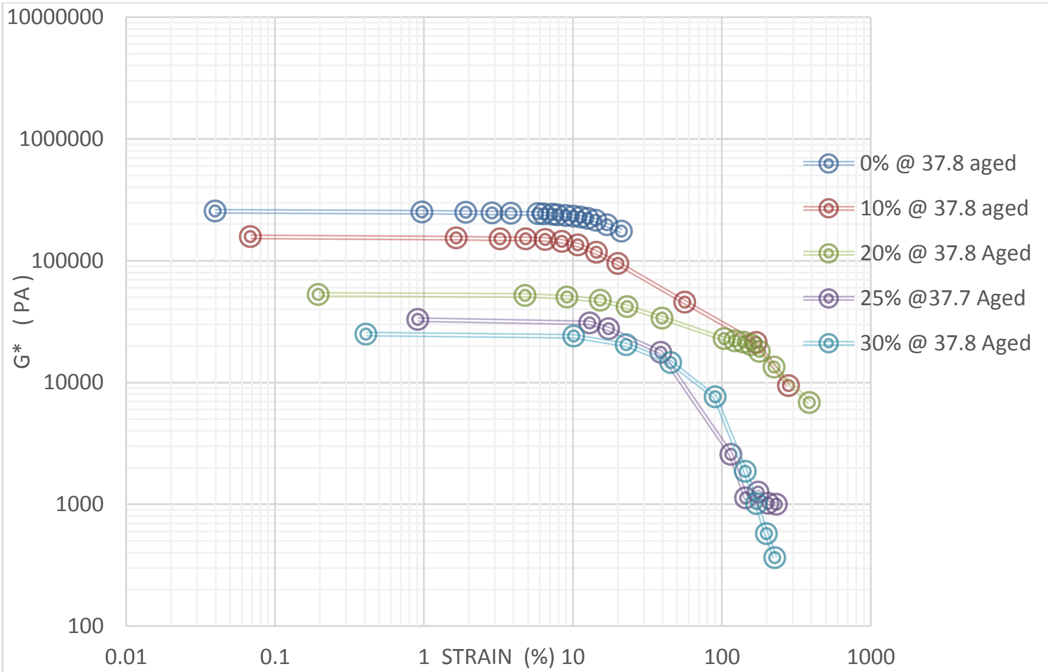


Figure A.3.The effect of Waste Tire on asphalt aged binder at 37.8^{o}C

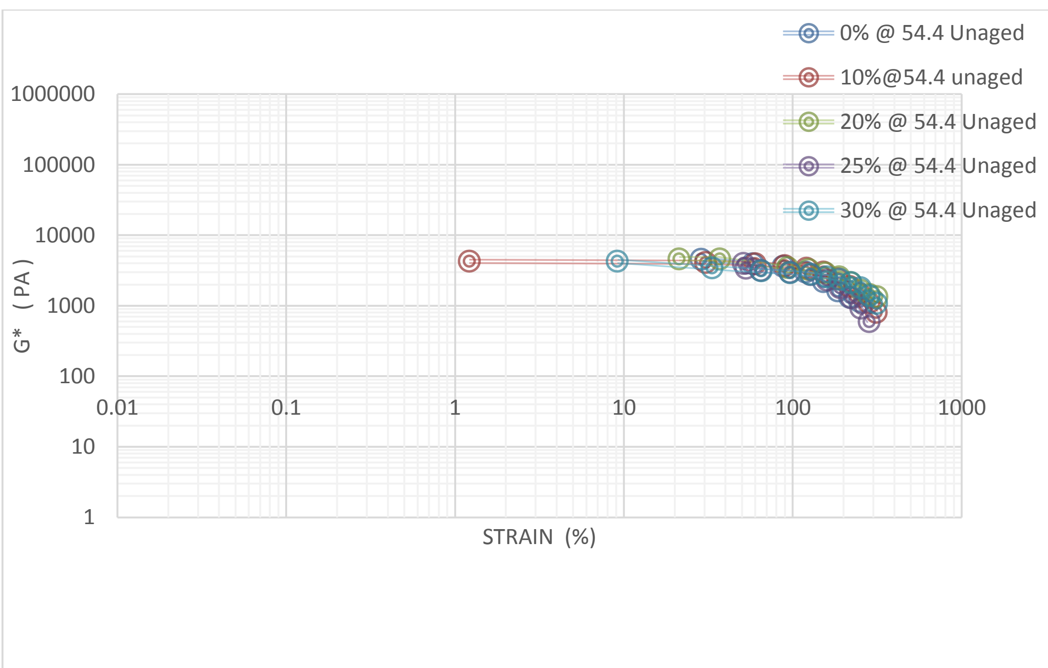


Figure A.4. The effect of Waste Tire on asphalt unaged binder at 54.4^{o}C

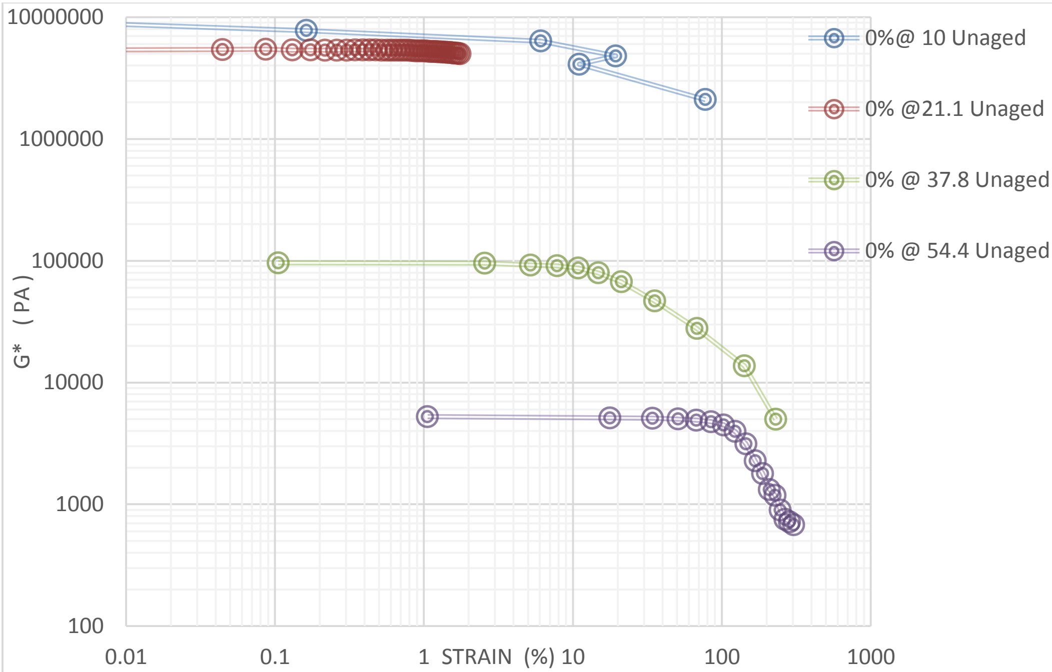


Figure A.5 AST Result of unaged 0% Waste Tire

Appendix B - Frequency Sweep Test Results

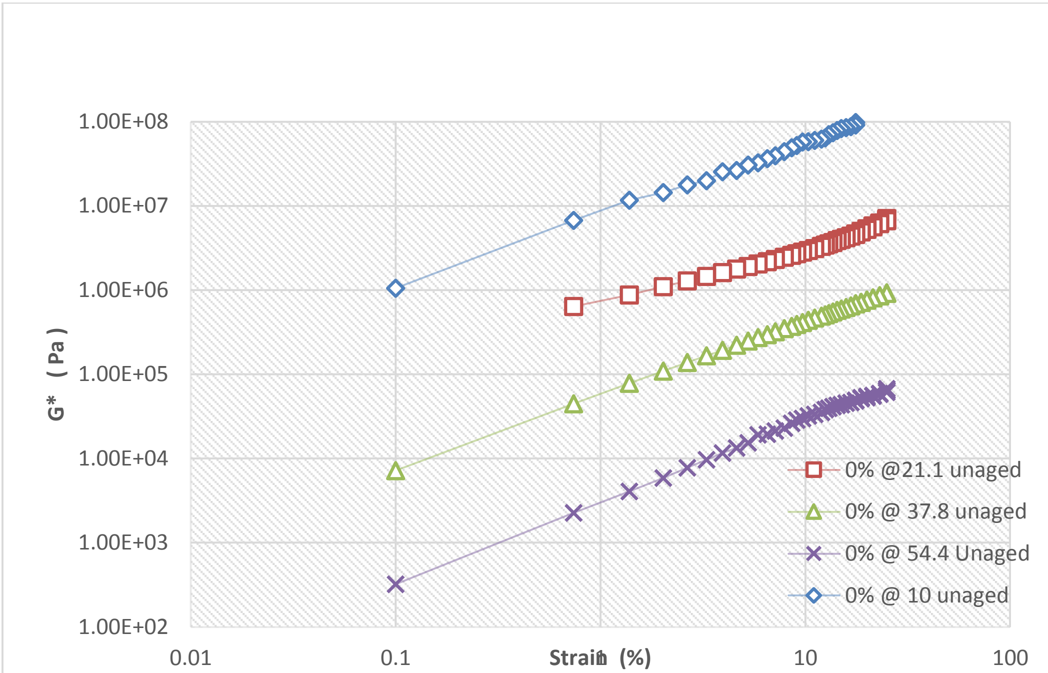


Figure B.1. Frequency Sweep test at 0% unaged

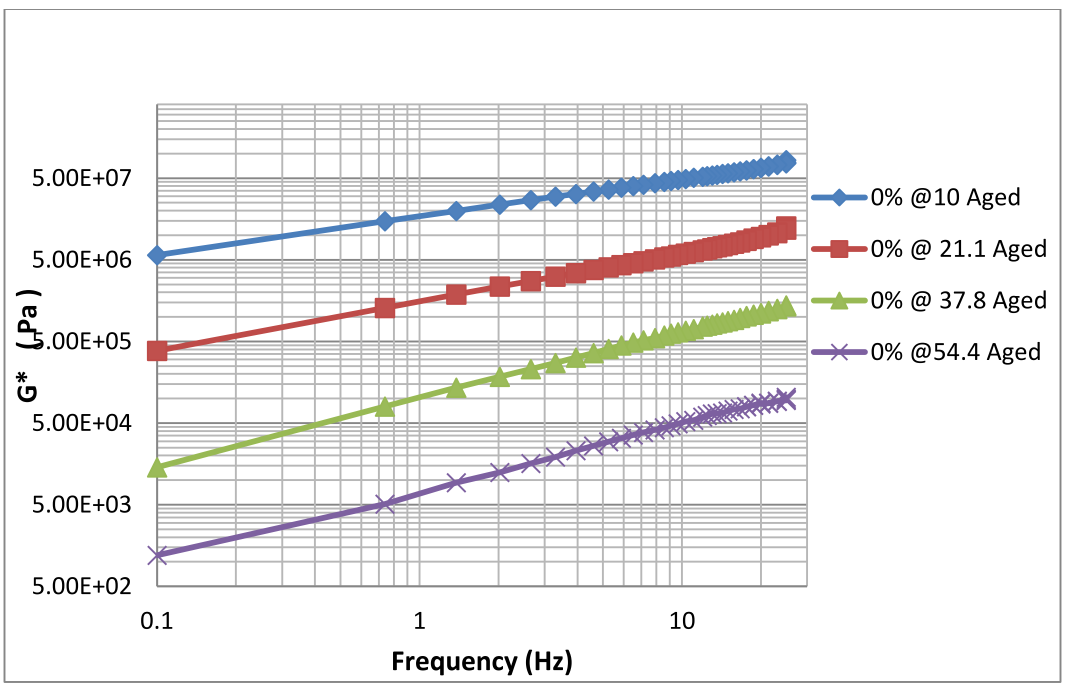


Figure B.2. Frequency Sweep test at 0% age

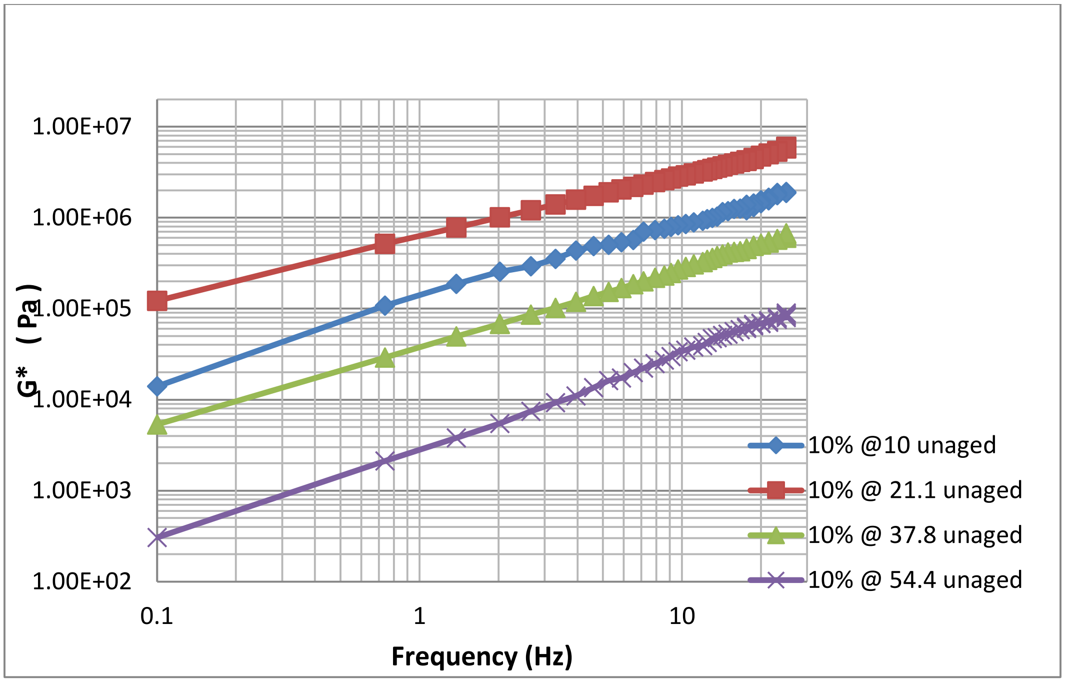


Figure B.3. Frequency Sweep test at 10% unaged

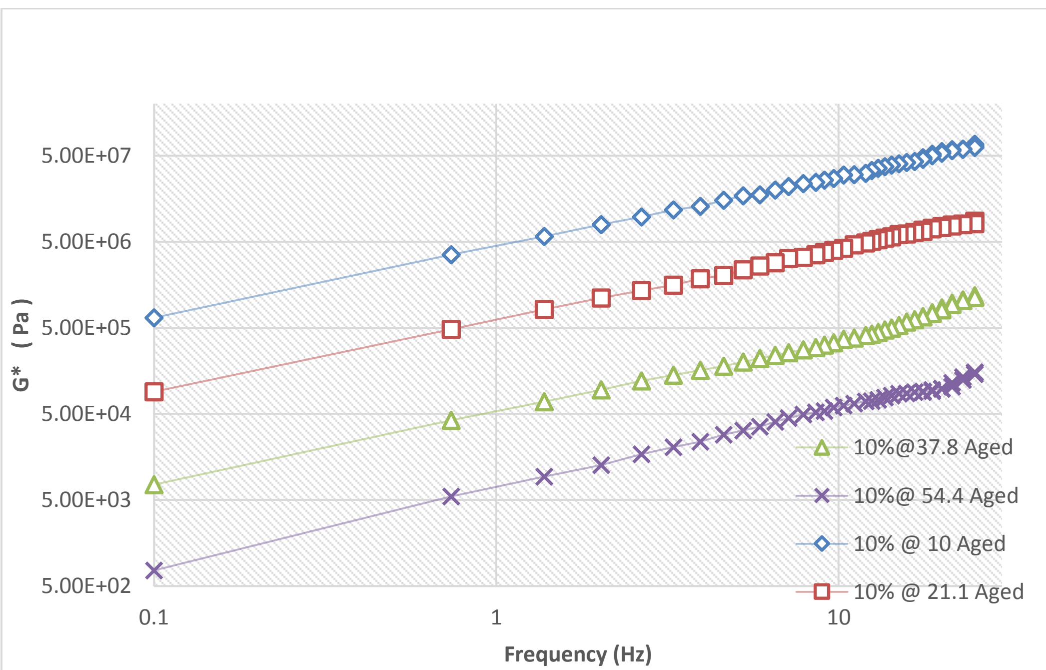


Figure B.4. Frequency Sweep test at 10% aged

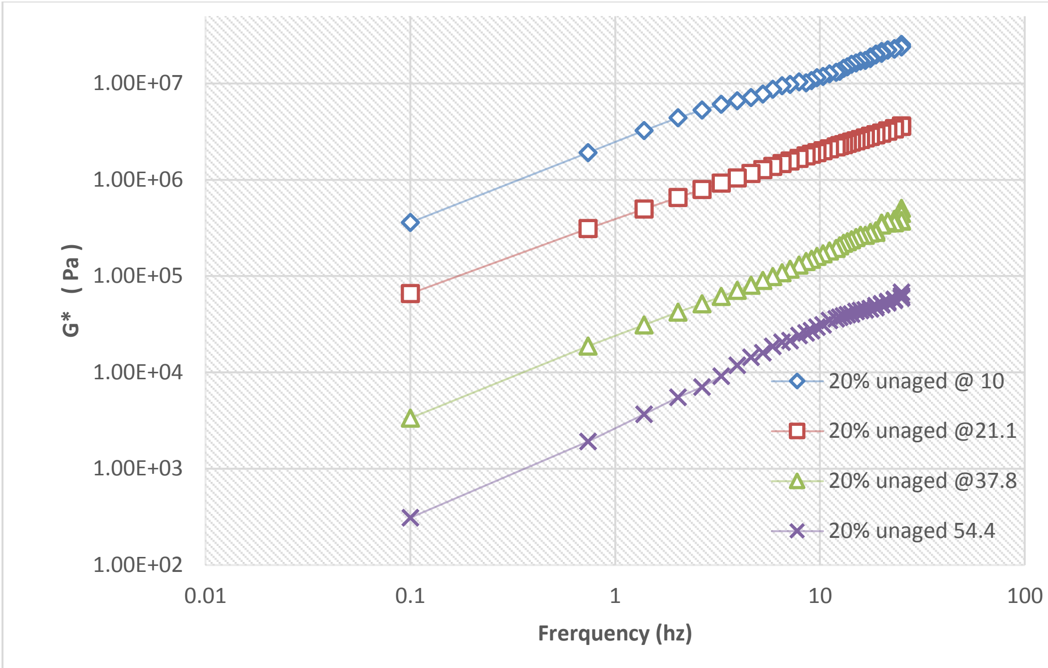


Figure B.5. Frequency Sweep test at 20% unaged

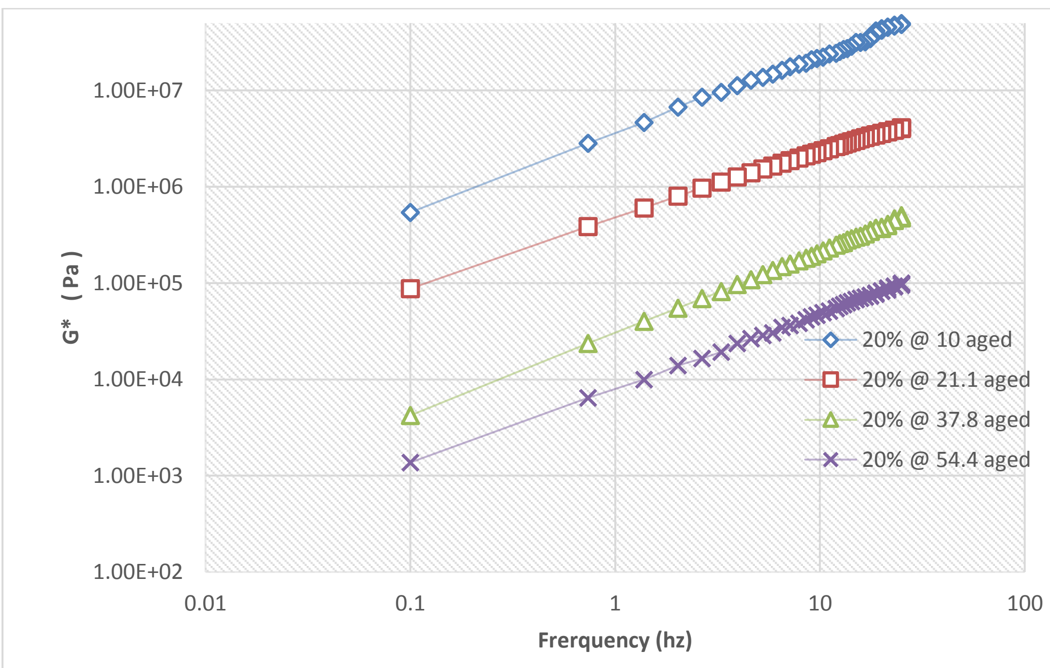


Figure B.6. Frequency Sweep Test at 20% aged

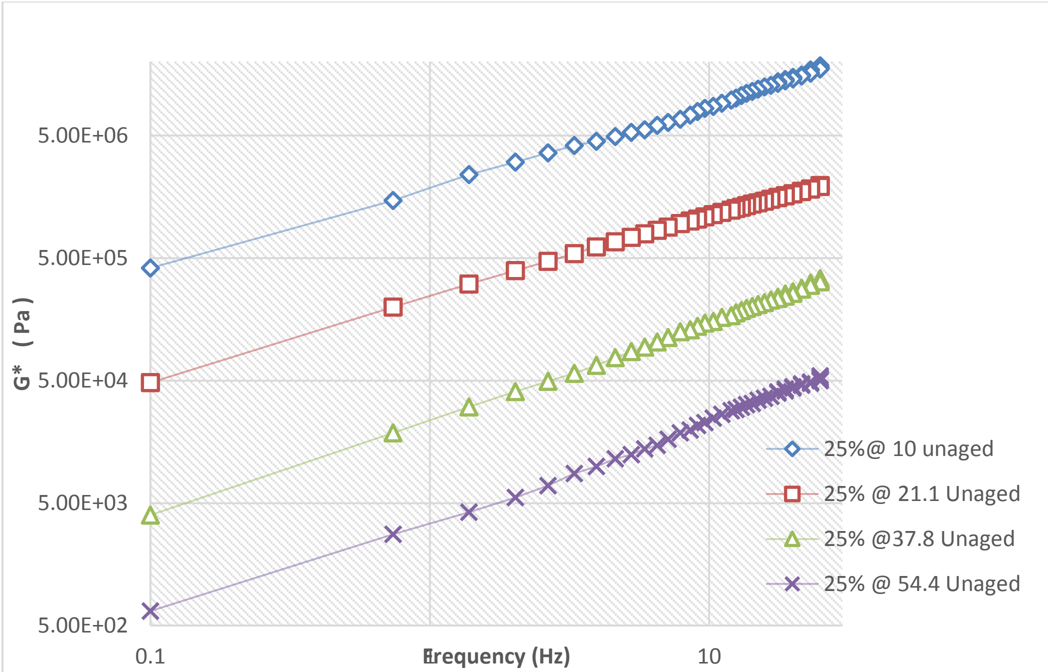


Figure B.7. Frequency Sweep test at 25% unaged

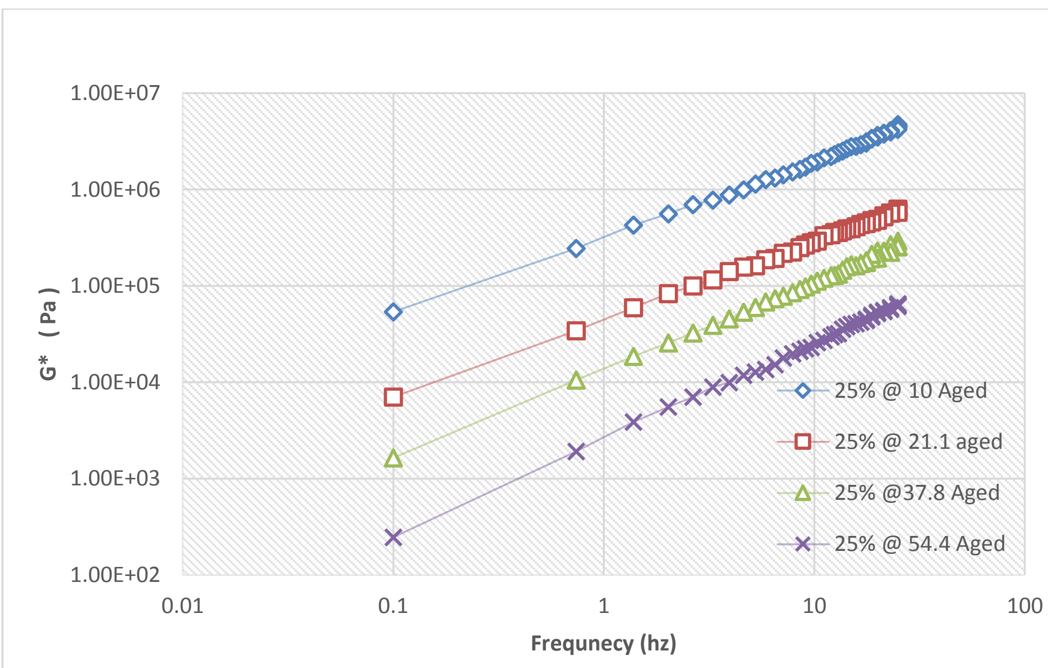


Figure B.8. Frequency Sweep test at 25% aged

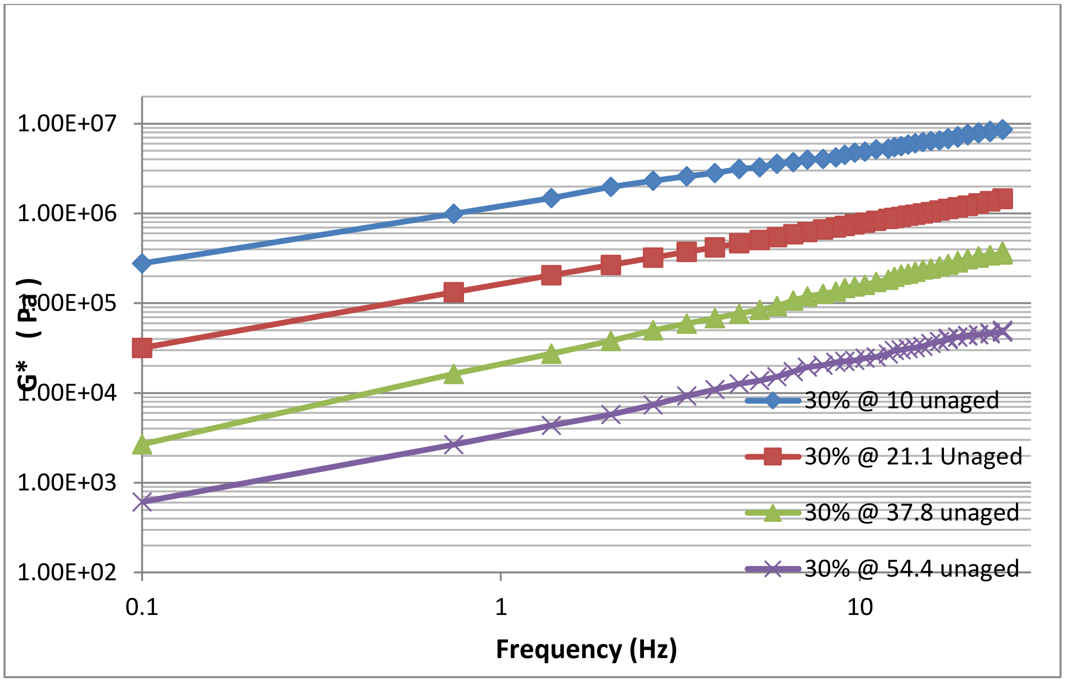


Figure B.9. Frequency Sweep Test at 30% unaged

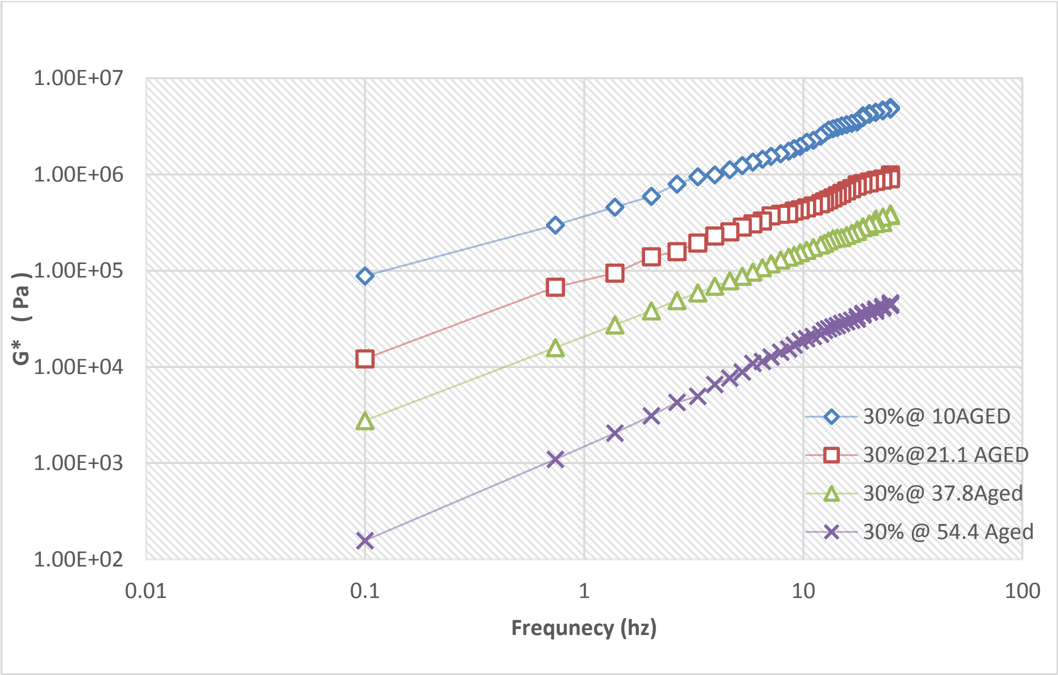


Figure B.10. Frequency Sweep Test at 30% aged

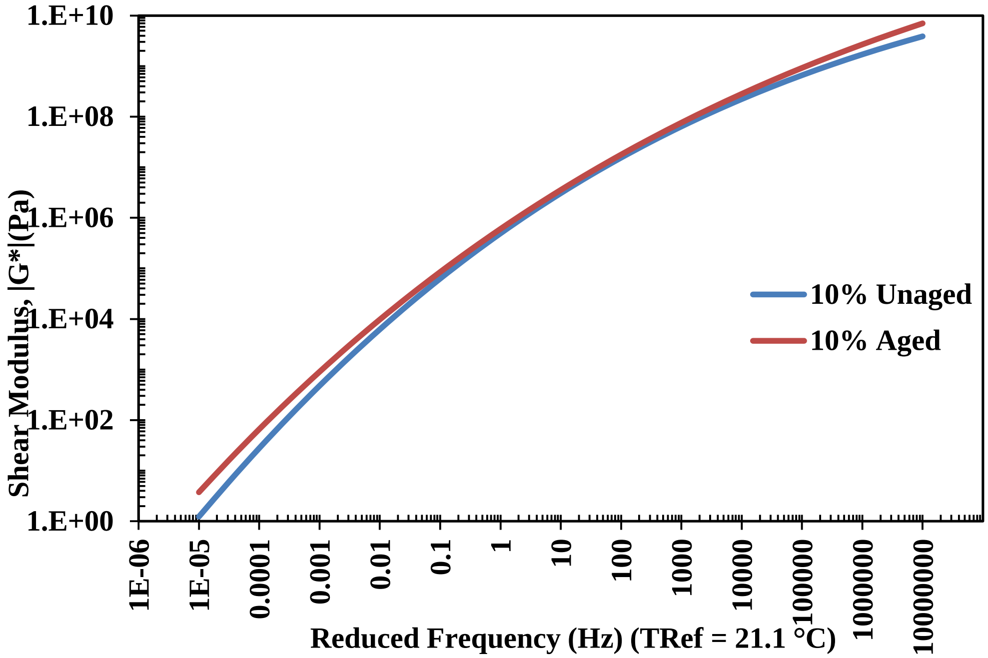


Figure B.11. The effect of aging on 10% Waste Tire binder

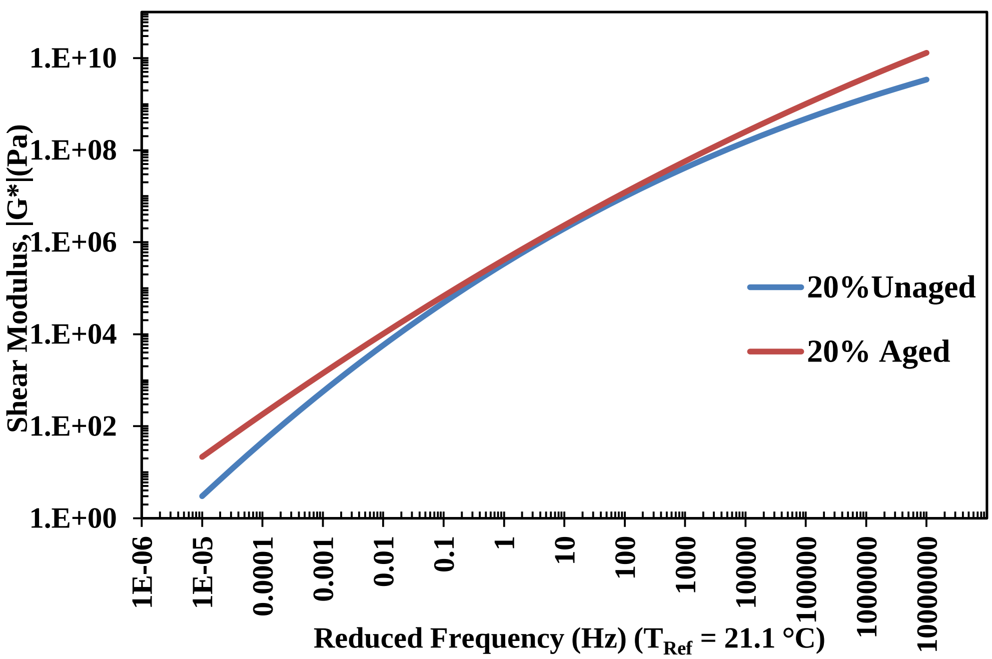


Figure B.12. The effect of aging on 20% Waste Tire binder

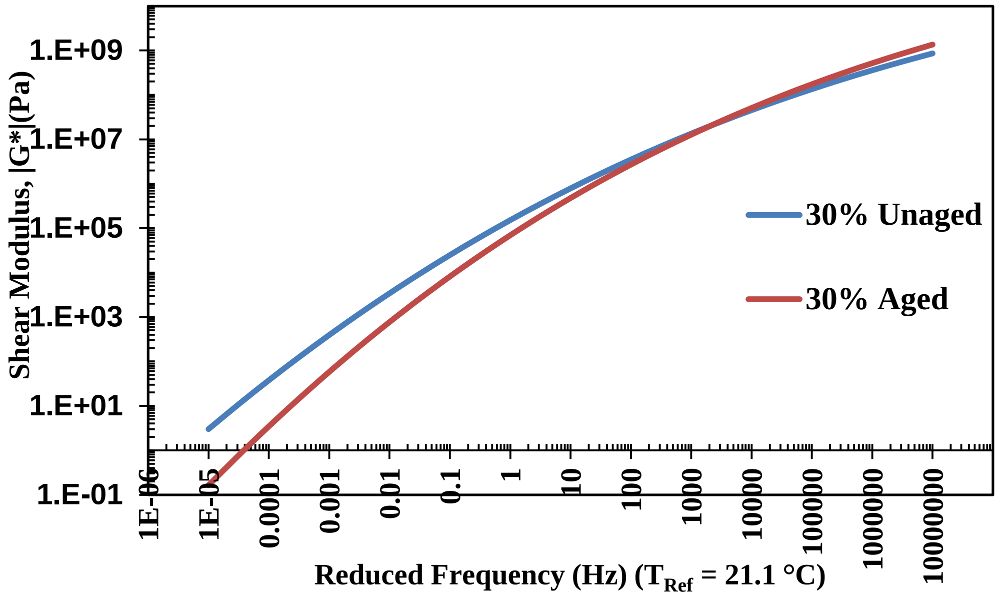


Figure B.13. The effect of aging on 30% Waste Tire binder

Appendix C - Performance Grade Test Result

Table C.1.Performance Grade Determination for 10% unaged asphalt binder

Time	Temperature	Frequency	Phase Angle	Complex Modulus	Elastic Modulus	Viscous Modulus	Complex Viscosity	Shear Stress	Strain
(s)	(°C)	(Hz)	(°)	(Pa)	(Pa)	(Pa)	(Pas)	(Pa)	( )
40.329	57.94	1.60E+00	84.34	3.71E+03	3.66E+02	3.70E+03	3.70E+02	4.28E+02	1.15E-01
40.31	64.05	1.60E+00	85.62	1.51E+03	1.16E+02	1.51E+03	1.51E+02	1.77E+02	1.17E-01
40.349	70.04	1.60E+00	86.44	7.21E+02	4.48E+01	7.20E+02	7.19E+01	8.30E+01	1.15E-01
Pass Fail Temp :	67.4								
Grade :	64								

Table C.2.Performance Grade Determination for 10% aged asphalt binder

Time	Temperature	Frequency	Phase Angle	Complex Modulus	Elastic Modulus	Viscous Modulus	Complex Viscosity	Shear Stress	Strain
(s)	(°C)	(Hz)	(°)	(Pa)	(Pa)	(Pa)	(Pas)	(Pa)	( )
40.331		1.60E+00	84.1	5.49E+03	5.65E+02	5.46E+03	5.48E+02	8.20E+02	1.49E-01

	58.08								
39.733	63.98	1.60E+00	85.69	2.80E+03	2.10E+02	2.79E+03	2.79E+02	3.49E+02	1.25E-01
40.33	69.91	1.60E+00	87.04	1.11E+03	5.35E+01	1.03E+03	1.03E+02	1.44E+02	1.39E-01
Pass Fail Temp :	66.2								
Grade :	64								

Table C.3. Performance Grade Determination for 20% unaged asphalt binder

Time	Temperature	Frequency	Phase Angle	Complex Modulus	Elastic Modulus	Viscous Modulus	Complex Viscosity	Shear Stress	Strain
(s)	(°C)	(Hz)	(°)	(Pa)	(Pa)	(Pa)	(Pas)	(Pa)	( )
40.487	58.03	1.60E+00	76.81	2.81E+03	6.42E+02	2.74E+03	2.81E+02	3.53E+02	1.26E-01
40.363	63.91	1.60E+00	73.58	1.51E+03	4.26E+02	1.45E+03	1.50E+02	1.82E+02	1.22E-01
40.355	70.09	1.60E+00	68.04	8.42E+02	3.15E+02	7.81E+02	8.40E+01	9.87E+01	1.20E-01
Pass Fail Temp :	69								
Grade :	64								

Table C.4. Performance Grade Determination for 20% aged asphalt binder

Time	Temperature	Frequency	Phase Angle	Complex Modulus	Elastic Modulus	Viscous Modulus	Complex Viscosity	Shear Stress	Strain
(s)	(°C)	(Hz)	(°)	(Pa)	(Pa)	(Pa)	(Pas)	(Pa)	( )
40.354	58.11	1.60E+00	84.22	3.29E+03	3.31E+02	3.27E+03	3.28E+02	3.45E+02	1.05E-01
40.369	64.02	1.60E+00	85.68	1.42E+03	1.07E+02	1.42E+03	1.42E+02	1.67E+02	1.18E-01
40.92	69.97	1.60E+00	86.51	1.34E+03	3.92E+01	6.43E+02	6.43E+01	7.85E+01	1.22E-01
Pass Fail Temp :	66.7								
Grade :	64								

Table C.5. Performance Grade Determination for 25%unaged asphalt binder

Time	Temperature	Frequency	Phase Angle	Complex Modulus	Elastic Modulus	Viscous Modulus	Complex Viscosity	Shear Stress	Strain
(s)	(°C)	(Hz)	(°)	(Pa)	(Pa)	(Pa)	(Pas)	(Pa)	( )
40.334	58.08	1.60E+00	76.41	2.94E+03	6.92E+02	2.86E+03	2.94E+02	3.62E+02	1.24E-01
40.265	63.97	1.60E+00	75.93	1.77E+03	4.31E+02	1.72E+03	1.77E+02	2.16E+02	1.23E-01
40.386	69.95	1.60E+00	75.42	1.05E+03	2.63E+02	1.01E+03	1.04E+02	1.24E+02	1.20E-01
40.314	75.88	1.60E+00	74.67	6.02E+02	1.59E+02	5.81E+02	6.00E+01	6.99E+01	1.18E-01
Pass Fail Temp :	75.8								
Grade :	70								

Table C.6. Performance Grade Determination for 25% aged asphalt binder

Time	Temperature	Frequency	Phase Angle	Complex Modulus	Elastic Modulus	Viscous Modulus	Complex Viscosity	Shear Stress	Strain
(s)	(°C)	(Hz)	(°)	(Pa)	(Pa)	(Pa)	(Pas)	(Pa)	( )
40.355	57.95	1.60E+00	84.72	3.72E+03	2.50E+02	3.71E+03	3.71E+02	4.28E+02	1.21E-01
40.368	63.9	1.60E+00	85.65	2.21E+03	9.22E+01	2.21E+03	1.21E+02	2.52E+02	1.25E-01
40.314	69.95	1.60E+00	86.7	1.21E+03	3.22E+01	1.21E+03	7.80E+01	1.45E+02	1.25E-01
Pass Fail Temp	69.45								
Grade :	64								

Table C.7.Performance Grade Determination for 30% unaged asphalt binder

Time	Temperature	Frequency	Phase Angle	Complex Modulus	Elastic Modulus	Viscous Modulus	Complex Viscosity	Shear Stress	Strain
(s)	(°C)	(Hz)	(°)	(Pa)	(Pa)	(Pa)	(Pas)	(Pa)	( )
40.367	57.96	1.60E+00	77.07	3.16E+03	7.06E+02	3.08E+03	3.15E+02	3.73E+02	1.18E-01
40.36	64.14	1.60E+00	76.36	1.53E+03	3.61E+02	1.49E+03	1.53E+02	2.07E+02	1.36E-01
40.367	70.08	1.60E+00	75.83	1.14E+03	2.78E+02	1.10E+03	1.13E+02	1.33E+02	1.18E-01
40.427	76.9	1.60E+00	74.19	5.37E+02	1.46E+02	5.17E+02	5.36E+01	6.13E+01	1.16E-01
Pass Fail Temp :	76.9								
Grade :	70								

Table C.8.Performance Grade Determination for 30% aged asphalt binder

Time	Temperature	Frequency	Phase Angle	Complex Modulus	Elastic Modulus	Viscous Modulus	Complex Viscosity	Shear Stress	Strain
(s)	(°C)	(Hz)	(°)	(Pa)	(Pa)	(Pa)	(Pas)	(Pa)	( )
40.329	58.05	1.60E+00	85.18	1.88E+03	1.58E+02	1.87E+03	1.87E+02	2.28E+02	1.22E-01
40.315	64.12	1.60E+00	85.45	1.11+03	6.87E+01	8.64E+02	8.65E+01	1.01E+02	1.17E-01
Pass Fail Temp :	63								
Grade :	58								

Appendix D. Multiple Stress Creep Recovery Test Results

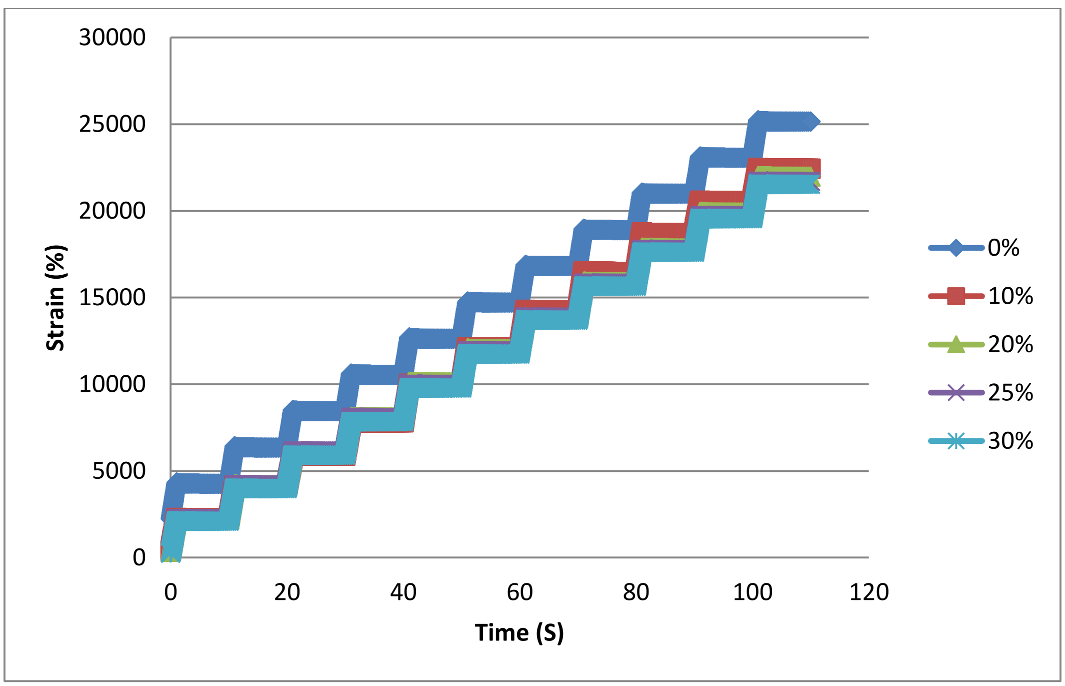


Figure D.1. Effect of Waste Tire on strain at 3.2 kPa (58^{o}C**)**

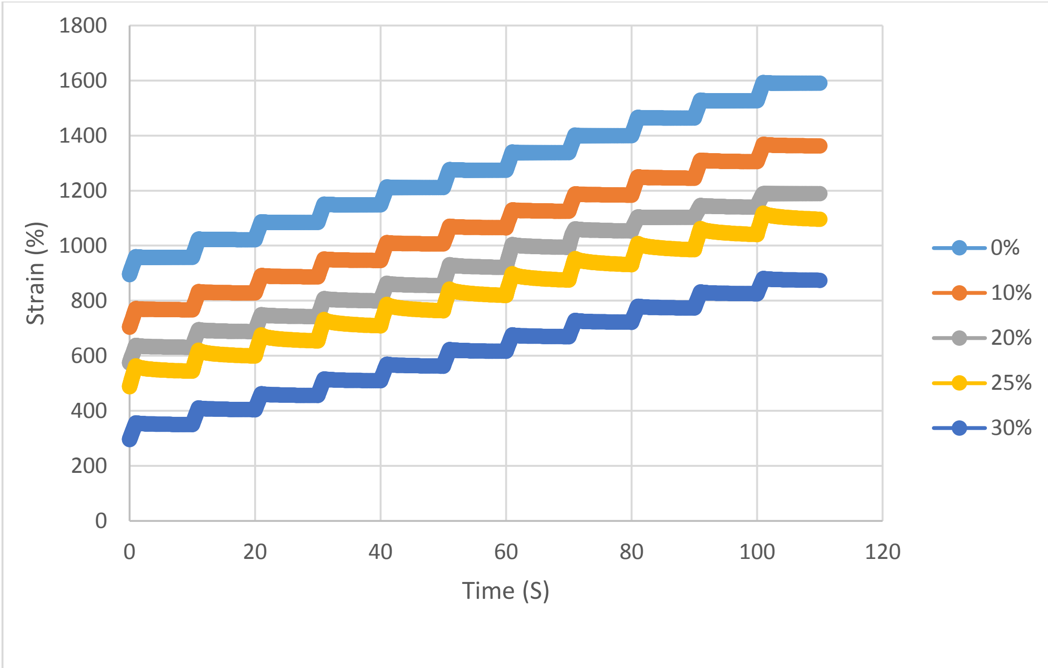


Figure D.2. Effect of Waste Tire on strain at 0.1 kPa 58^{o}C)

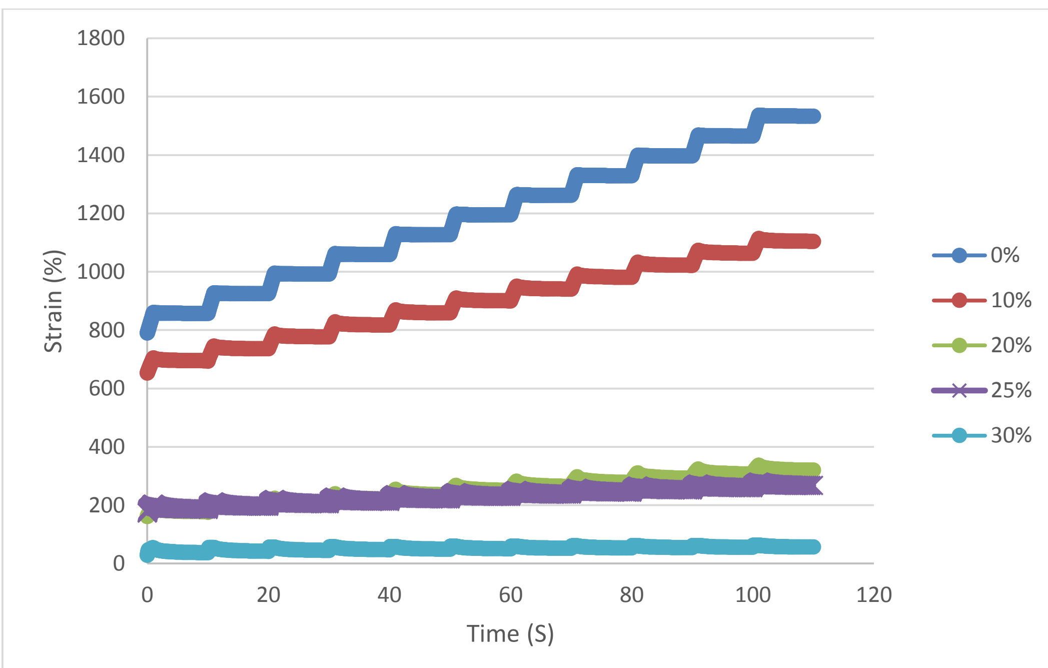


Figure D.3.Effect of Waste Tire on strain at 0.1 kPa (70^{o}C)

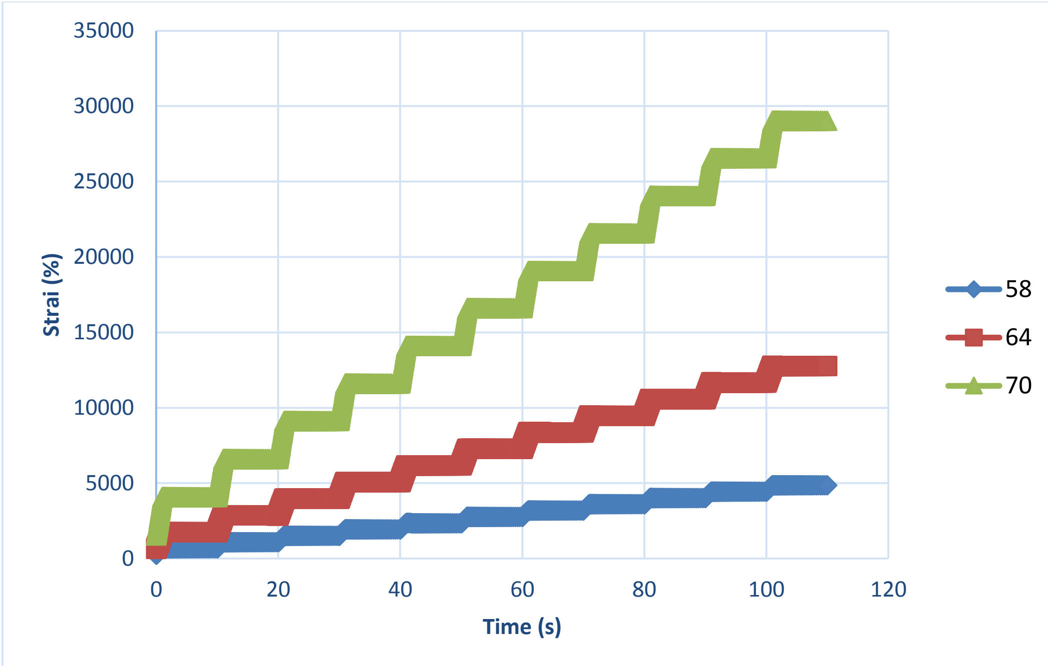


Figure D.4.0% Waste Tire at 3.2kpa stress

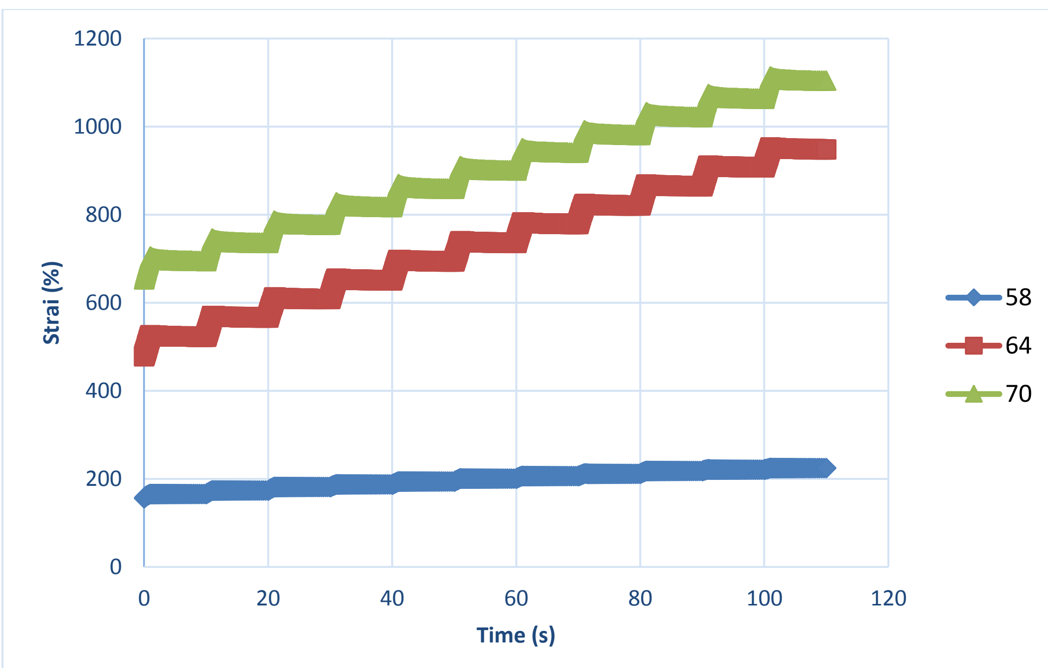


Figure D.5. 10% Waste Tire at 0.1 kpa stress

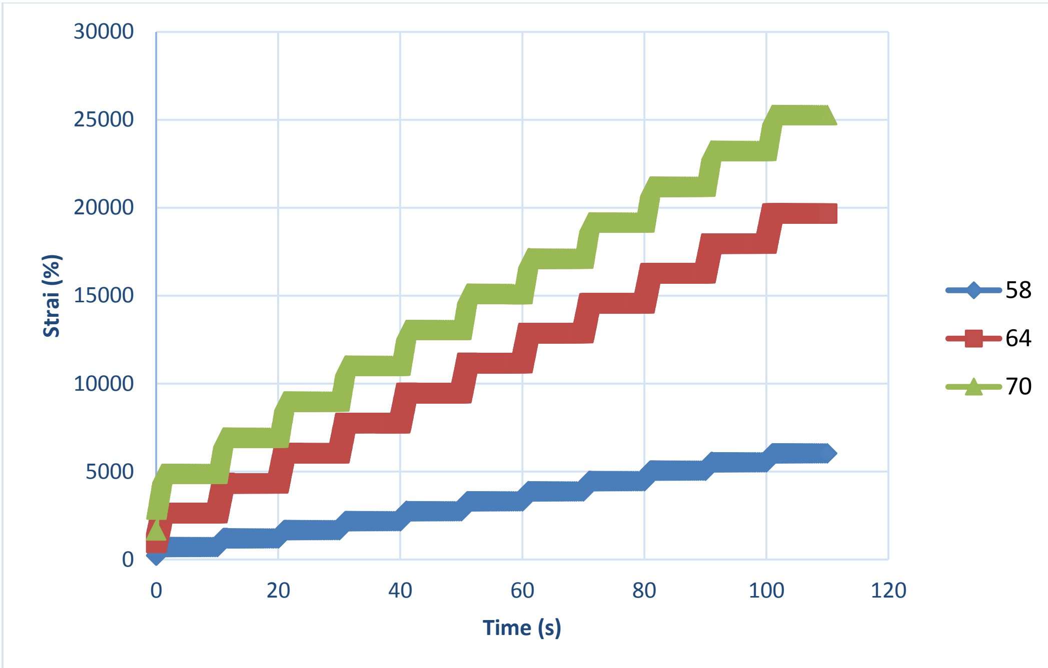
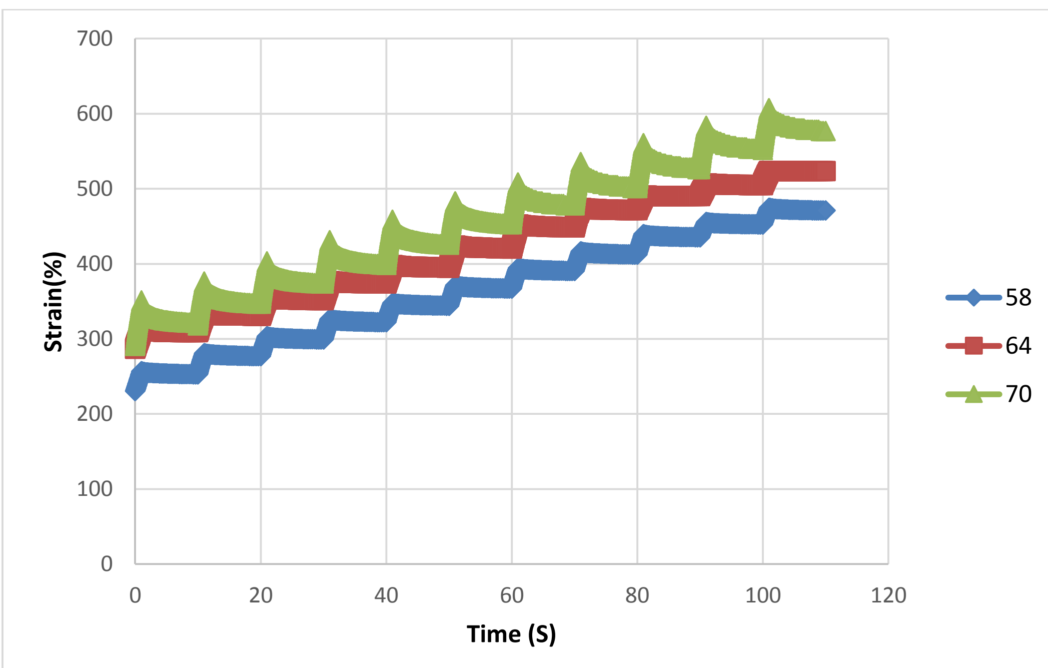
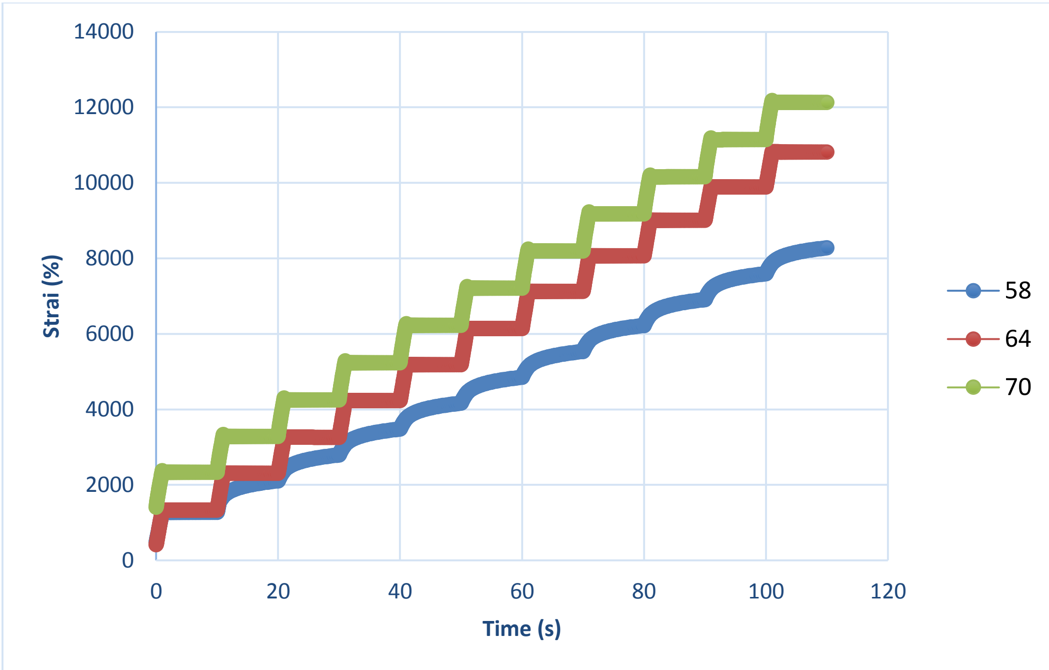


Figure D.6. 10% Waste Tire at 3.2kpa stress



FigureD.7. 20% Waste Tire at0.1 kpa stress



FigureD.8. 20% Waste Tire at 3.2kpa stress

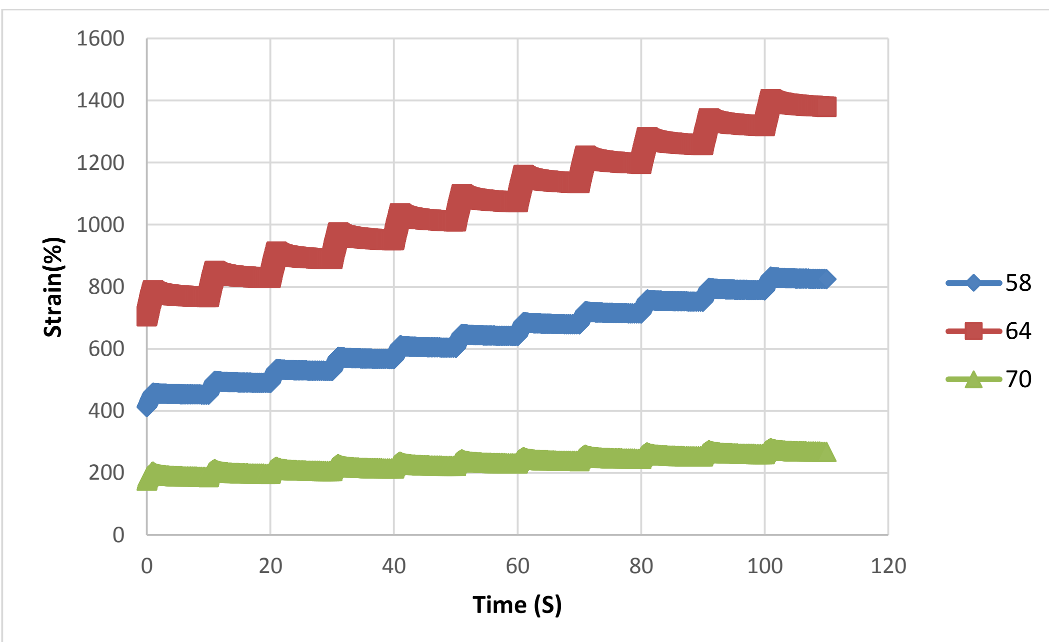


Figure D.9. 25% Waste Tire at 0.1 kpa stress

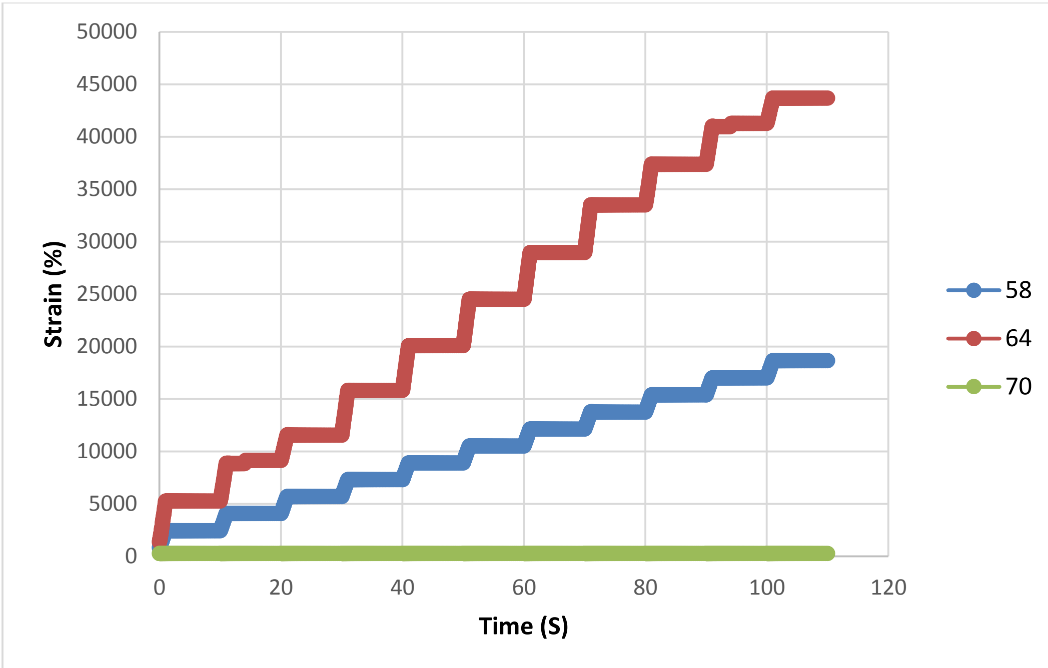


Figure D.10. Effect of temperature on MSCR for 25% waste tire content (3.2kPa)

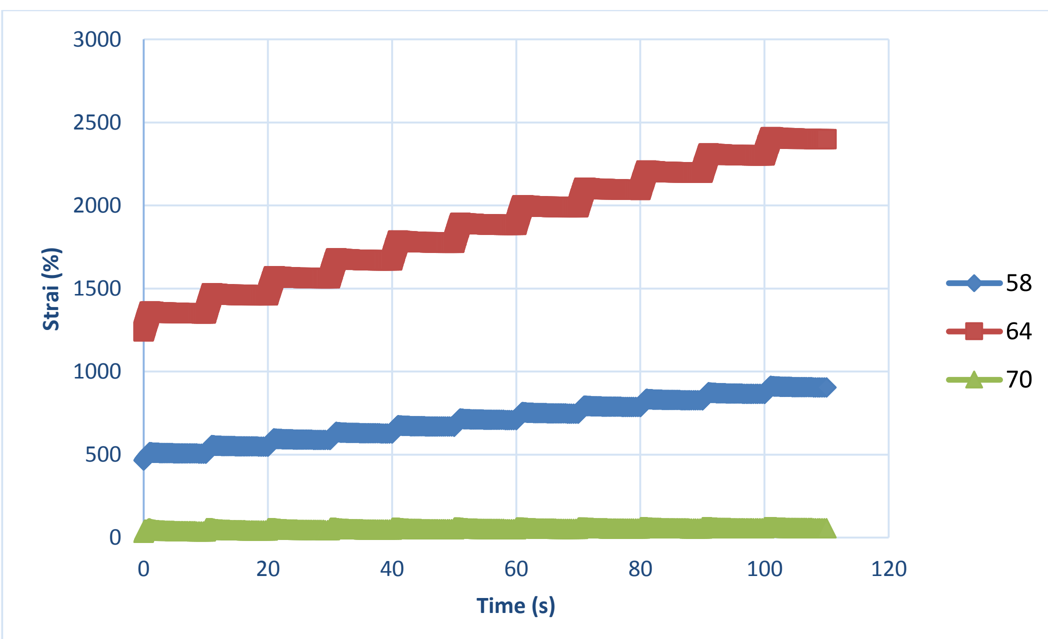
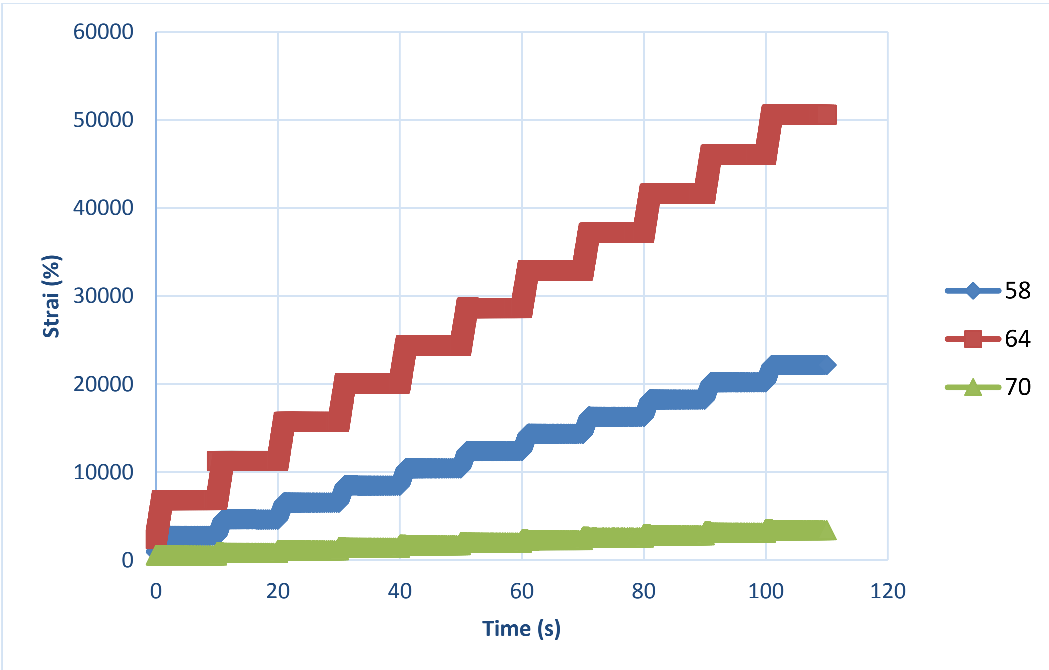


Figure D.11. 30% Waste Tire at 0.1 Kpa stress



FigureD.12. 30% Waste Tire at 3.2kpa stress

Appendix E. Graphical Representation of Mix Test Properties

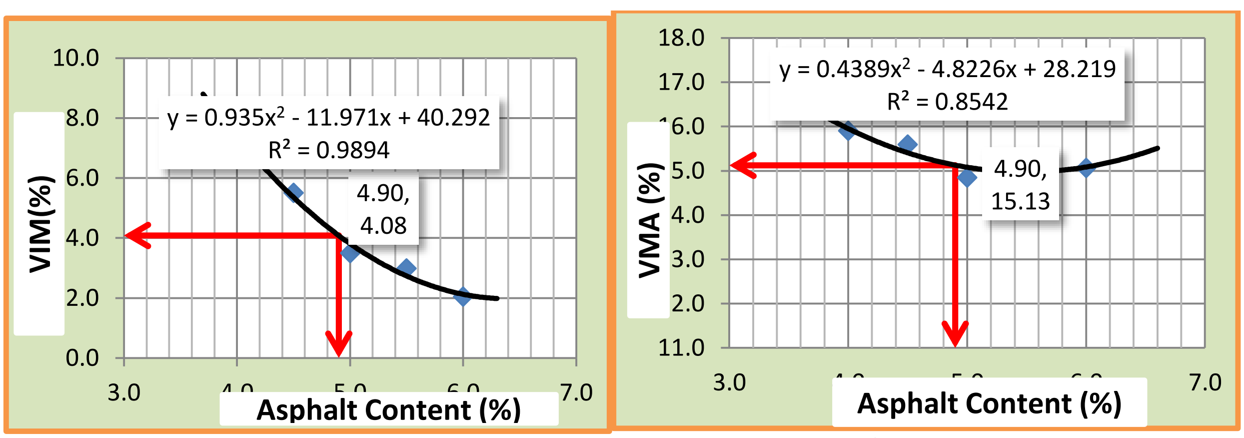


Figure E.1. Optimum Bitumen content determination of bitumen binder

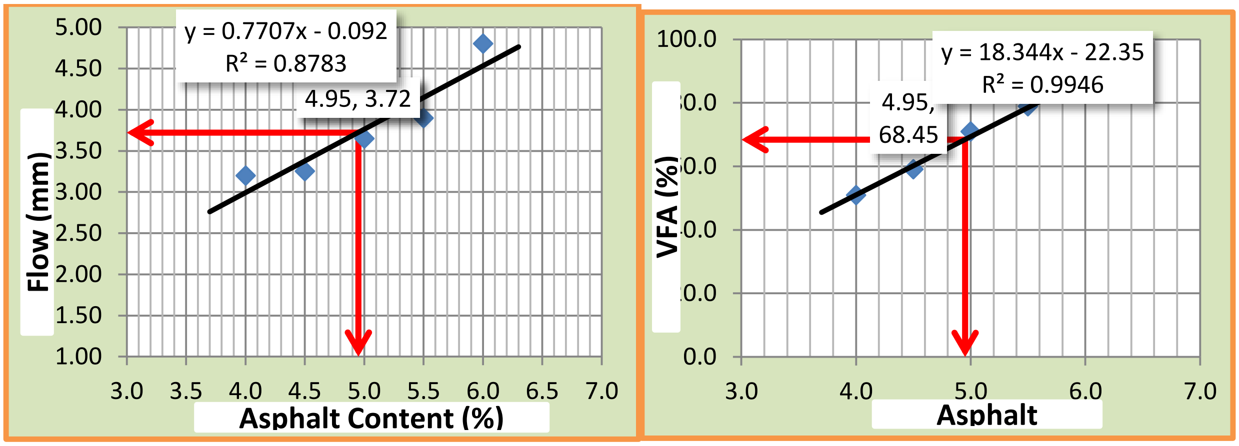


Figure E.2. Optimum Bitumen content determination of 20% Waste Tire

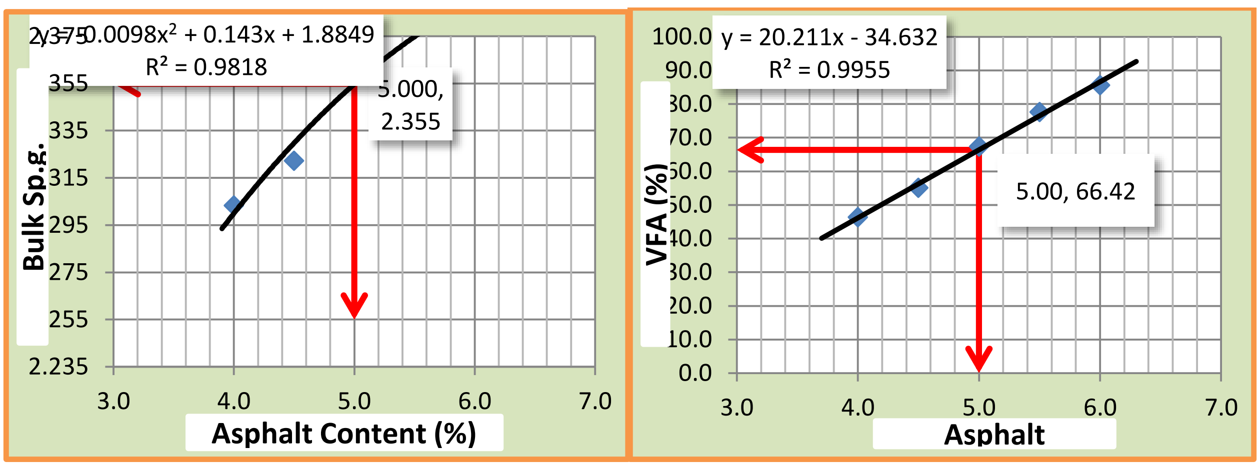


Figure E.3. Optimum Bitumen content determination of 25% Waste Tire

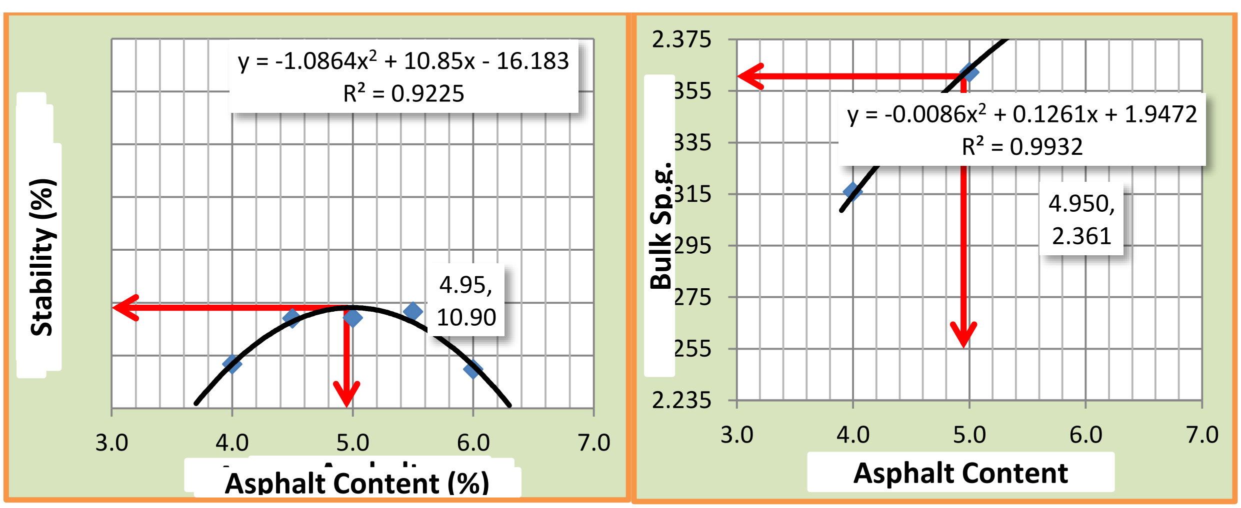


Figure E.4 Optimum Bitumen content determination of 30% Waste Tire

Appendix F Waste Tire sampling and Plant price including model and Quantity

TableF-1 of price, Model, product and Quantity of the Waste Tire production Plant

OUR COST	**CHIP TO 10 MESH PLANT FOR 2 TONS PER HOUR**				
Pricing	**No.**	**Products**	**Model**	**Power**	**Quantity**
$115000 MH Package	0	Material Handling MH Package for System	As Shown Below	As Shown Below	1 System
MH Package	1	Infeed Conveyor (steel)	800x5000mm	5.5KW	1 set
$485,000.00	2	Rasper 6060	Rasper 6060 or LGF66200	210KW	1 set
$4,000.00	3	Rasper Output Conveyor	1200x2000mm	1.1KW	1 set
$7,000.00	4	Steel Wire Magnet (Cross Belt Magnet)	500x1800mm	1.5KW	1 set
MH Package	5	Screw loader	WHD-2540	4KW	1 set
$125,000.00	6a	10 Mesh Granulator	PC52120	100KW	1 set
$125,000.00	6b	10 Mesh Granulator	PC52120	100KW	1 set
MH Package	7a	Vibrator(Fiber Separator)	1000x4000mm	1.5KW	1 set
MH Package	7b	Vibrator(Fiber Separator)	1000X4000mm	1.5KW	1 set
MH Package	8a	Fiber collecting unit A	200 liter	3KW	1 set
MH Package	8b	Fiber collecting unit B	200 liter	3 KW	1 set
MH Package	9a	Air loader		5.5KW	1 set
MH Package	9b	Air loader		5.5KW	1 set
$21,000.00	10a	Steel Wire Magnet (Cross Belt Magnet)	500 X 2000mm	1.5KW	1 set
$21,000.00	10b	Steel Wire Magnet (Cross Belt Magnet)	500 X 2000mm	1.5KW	1 set
MH Package	11a	Fine Fiber separator		0.75+0.75KW	1 set
MH Package	11b	Fine Fiber separator		0.75+0.75KW	1 set
$22,800.00	12a	Final Steel separator		0.55KW	1 set
$22,800.00	12b	Final Steel separator		0.55KW	1 set
MH Package	13	High pressure blower and hopper		3KW	1 set
MH Package	14	Water cooling system		7. 5kw	1set
MH Package	15	Dust collect center		11kw	1set
As Quoted in E Mails		Installation Supervision			1
As Quoted in E Mails		Installation Expenses			1

Included	18	Control panel and Motor Panel with Sensors for RPM and Temperature Control	CE/UL PROVED		1 set
$15,000.00	19	Test Visit	2 to 4 Days		1
$10,000.00	20	Startup Visit	2 to 4 days		1
SHIPPING	21	Ex works	6 containers est.		6

Table F.2. Waste Tire sampling

Addis Ababa				Outside Addis Ababa			
Car Types	No. of cars Sampling	AverageTire Change Frequencies	Sum	Car Types	No. of cars Sampling	Tire Change Frequencies	Sum
Automobile	20	3 years	60	Trucker	8	0.75 year	6
Pickup	10	1.5years	15	Pickup	10	1.25years	12.5
Minibus	10	1.5years	15	Minibus	10	1 year	10
Bus	10	1.5Years	15	Bus	10	1year	10
Total	50		105		38		38.5
Total average tire change		2.1 years		Total average Tire Change		1.01year	

Table F.3. Calculation table of cost benefit

year	Costs (Birr)	Benefit(Birr)	Net Undiscounted Cash Flows
1	61,524,410.40	76,876,800.00	15,352,389.60
2	72598804.27	87639552	15,040,747.73
3	85666589.04	99909089.28	14,242,500.24
4	101086575.1	113896361.8	12,809,786.71
5	119282158.6	129841852.4	10,559,693.85